Stratospheric Influence on Surface Ozone in the Southwestern U.S.

How important is it and why the Southwest?

Andrew O. Langford

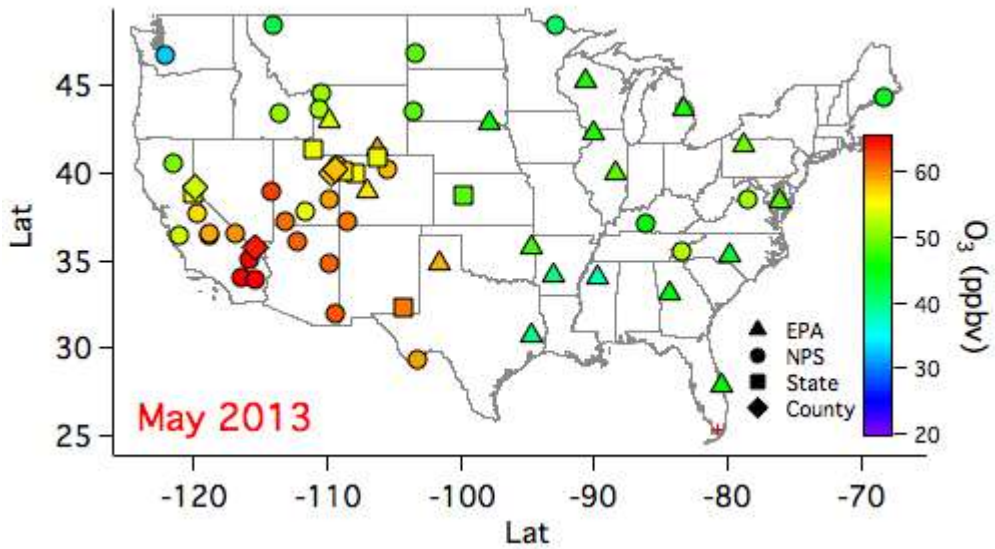
NOAA ESRL Chemical Sciences Division,

Boulder, CO

TOLNet

Ozone concentrations in Desert SW approach 2015 NAAQS in late spring

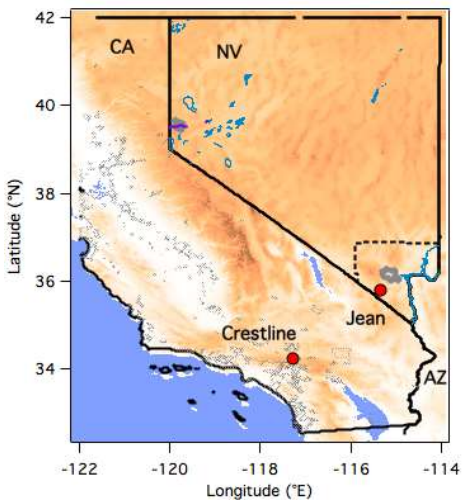
Mean MDA8 O_3 in May >**60 ppbv** in remote areas

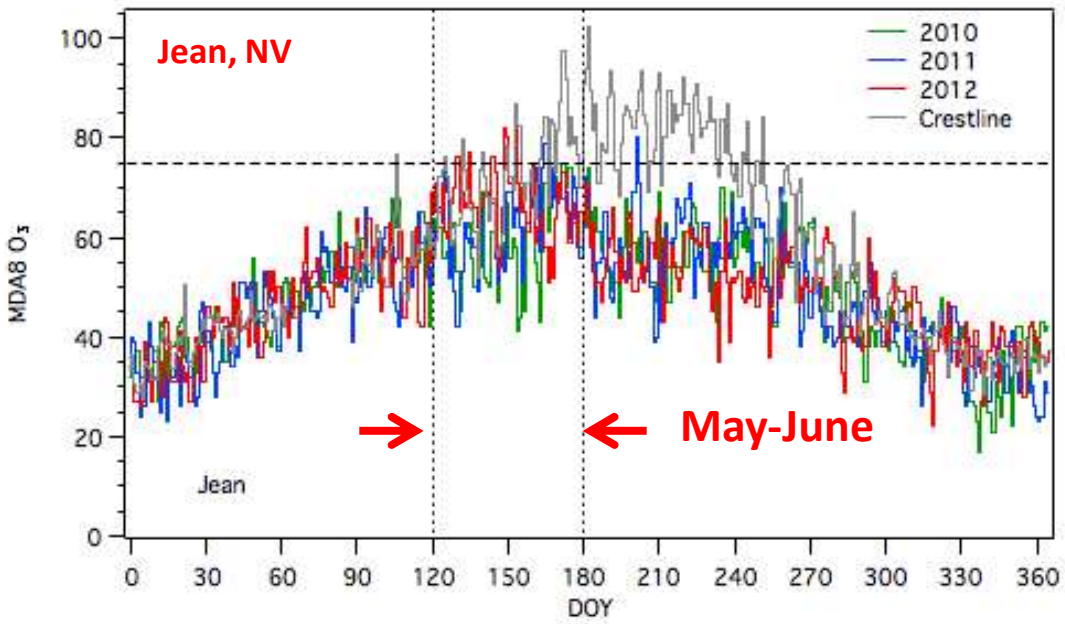


Where does this O_3 come from?

Los Angeles? Asia? Wildfires? Stratosphere?

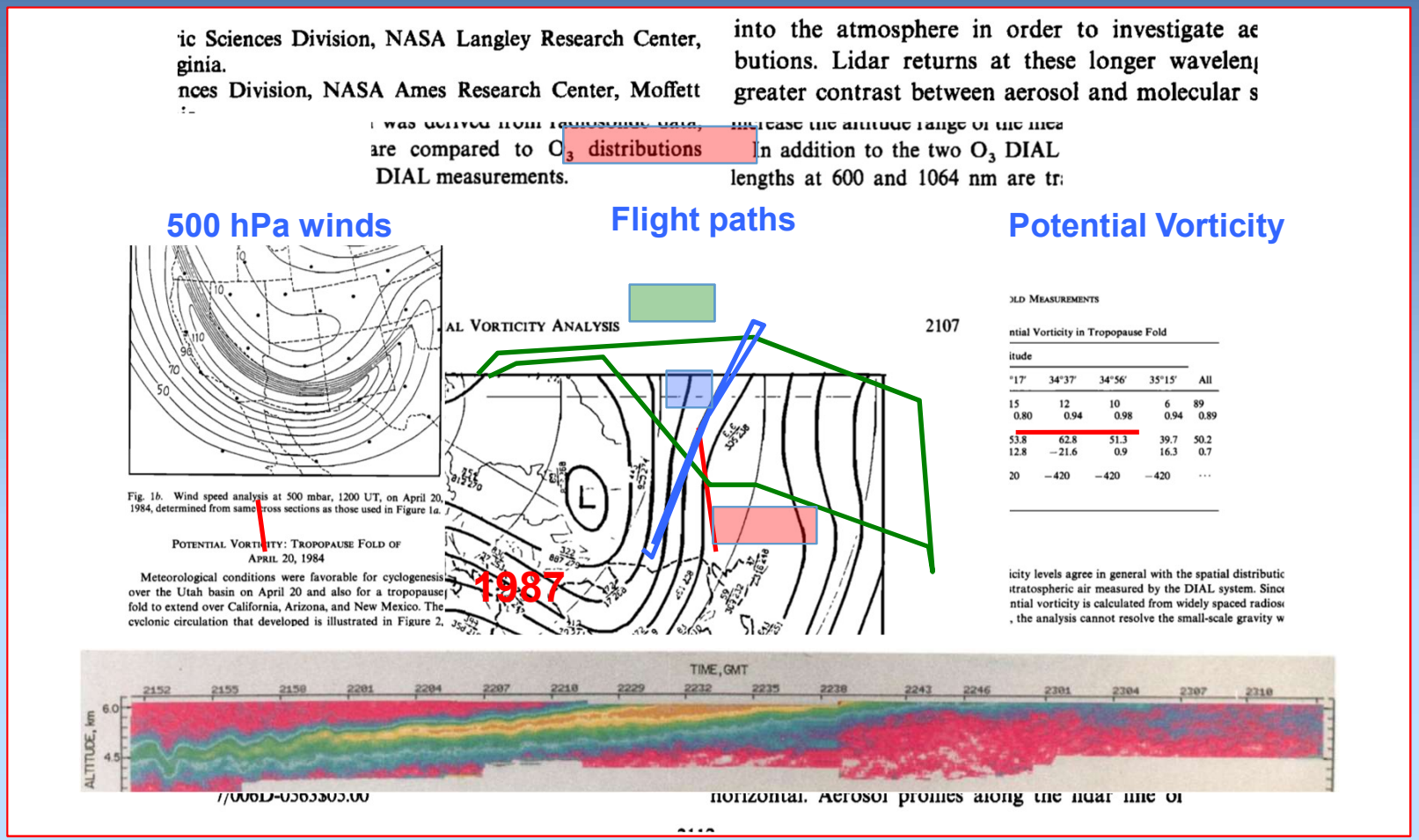
Late spring maximum inconsistent with local production or transport from Los Angeles





Background ozone across entire SW in May

Stratosphere-to-Troposphere Transport (STT) by tropopause folding

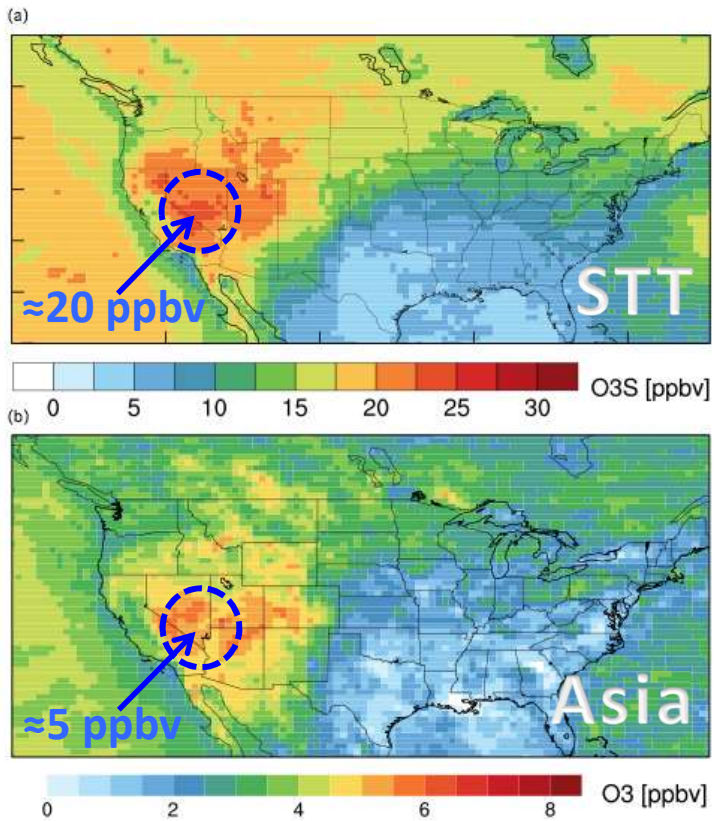


Tongues of lower stratospheric air slope that equatorward and downward beneath the jet stream

Tropopause folds 101

- Primarily develop during cyclogenesis (spin up or re-intensification of midlatitude cyclones)
- Occur year round, but most common in winter-spring
- Greatest impact on tropospheric ozone in springtime (more ozone in the lower stratosphere)
- Most dissipated in the free troposphere and add to regional and hemispheric background
- Deeper intrusions may directly increase surface concentrations (cold fronts, entrainment, …)

Descending tropopause folds entrain Asian pollution



Mean contributions to surface O_3 during CalNex (May-June 2010)

AM3 model Meiyun Lin (NOAA/GFDL/Princeton)

Stratospheric influx is 4x Asian transport

Las Vegas Ozone Study (LVOS)

Why? Do stratospheric intrusions and transport from Asia contribute to high O_3 in Clark County (Las Vegas), NV?

Who? NOAA ESRL Chemical Sciences Division with model support from NOAA/NESDID (RAQMS) and GFDL (AM3) and ($$) support from NOAA, Clark County, and TOLNet.

What? TOPAZ truck-mounted scanning ozone lidar (TOLNet) with in situ O_3, CO, and meteorology

Where? Angel Peak, Nevada (2.7 km asl)

When? May 19-June 26, 2013

LVOS
Las Vegas Ozone Study

Measurements at Angel Peak, NV (36.32° N,-115.57° E, 2.68 km ASL)

Former USAF Radar facility 45 km NW of downtown Las Vegas

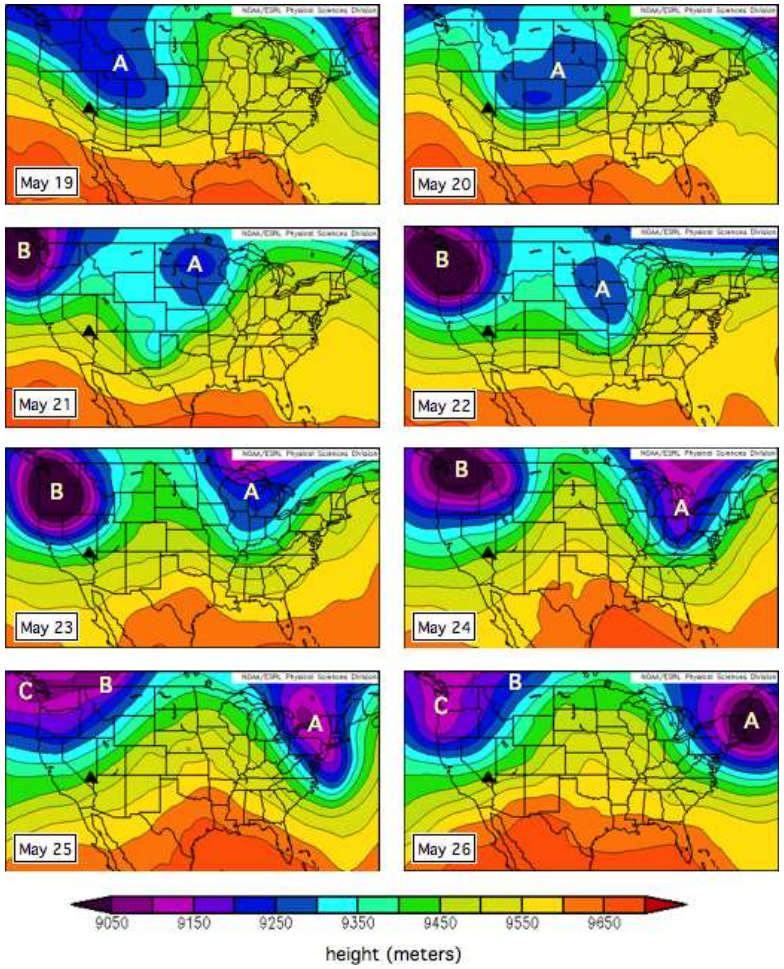
LVOS measurements at Angel Peak

LVOS
Las Vegas Ozone Study

In situ O_3 and CO meteorology at surface

Synoptic Background (May 19-26, 2013)

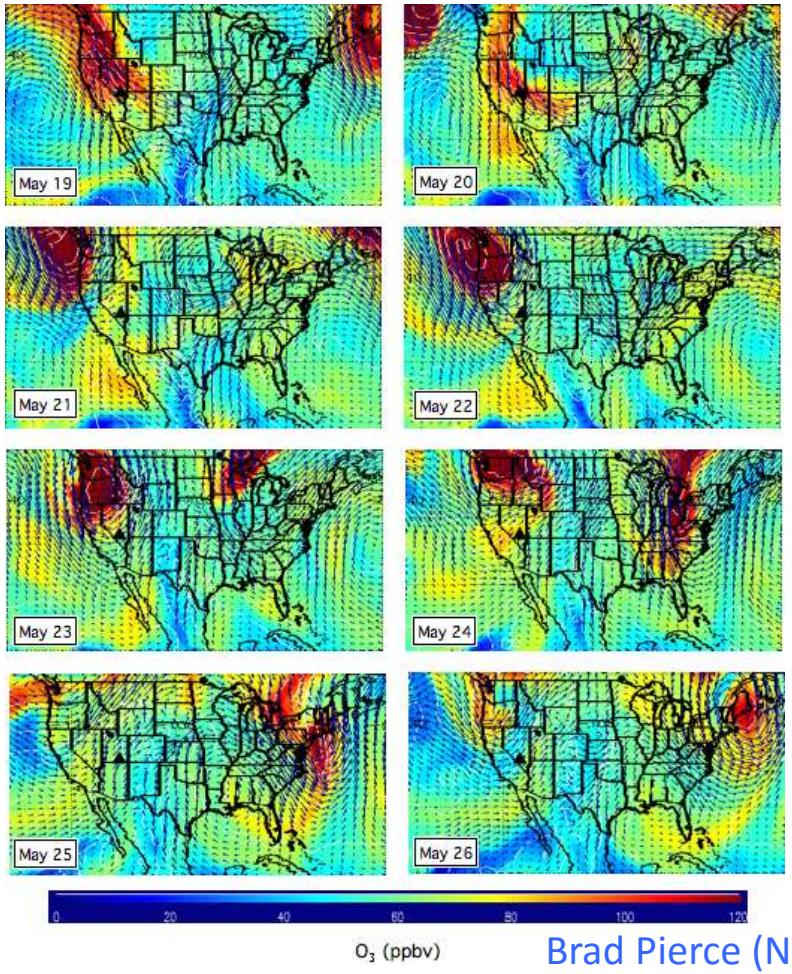
NCEP/NARR Reanalysis 12UT 300 hPa heights



3 deep midlatitude cyclones in one week

Synoptic Background (May 19-26, 2013)

NOAA/NESDIS RAQMS 12UT 310K O_3 distributions

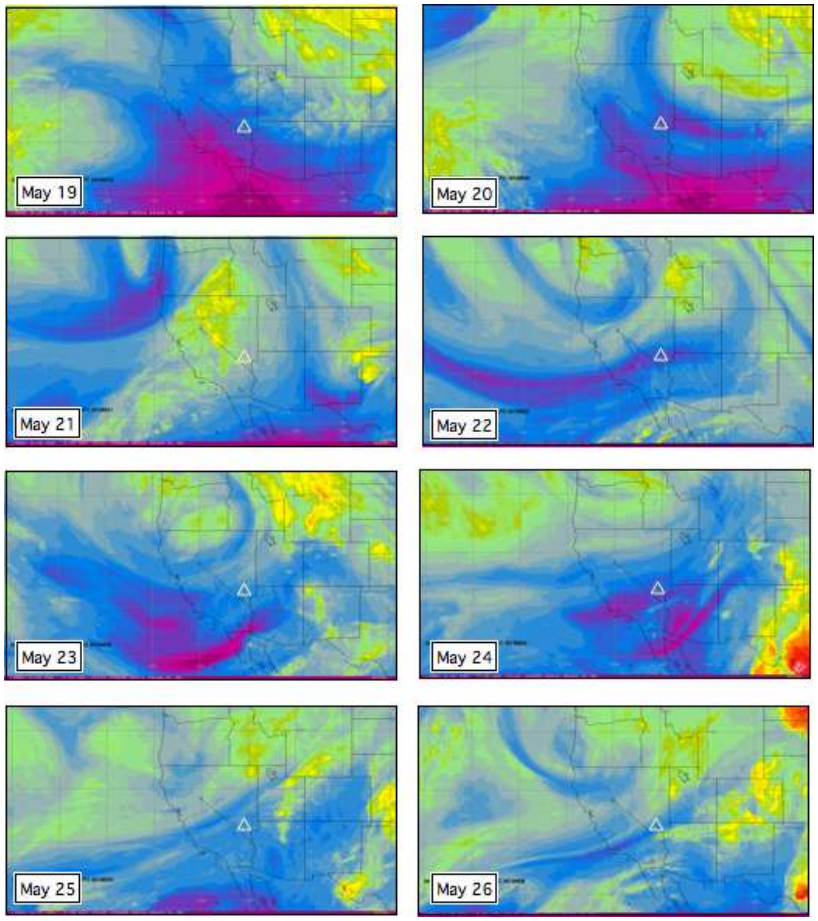


Brad Pierce (NOAA/NESDIS)

Multiple high O_3 filaments above U.S.

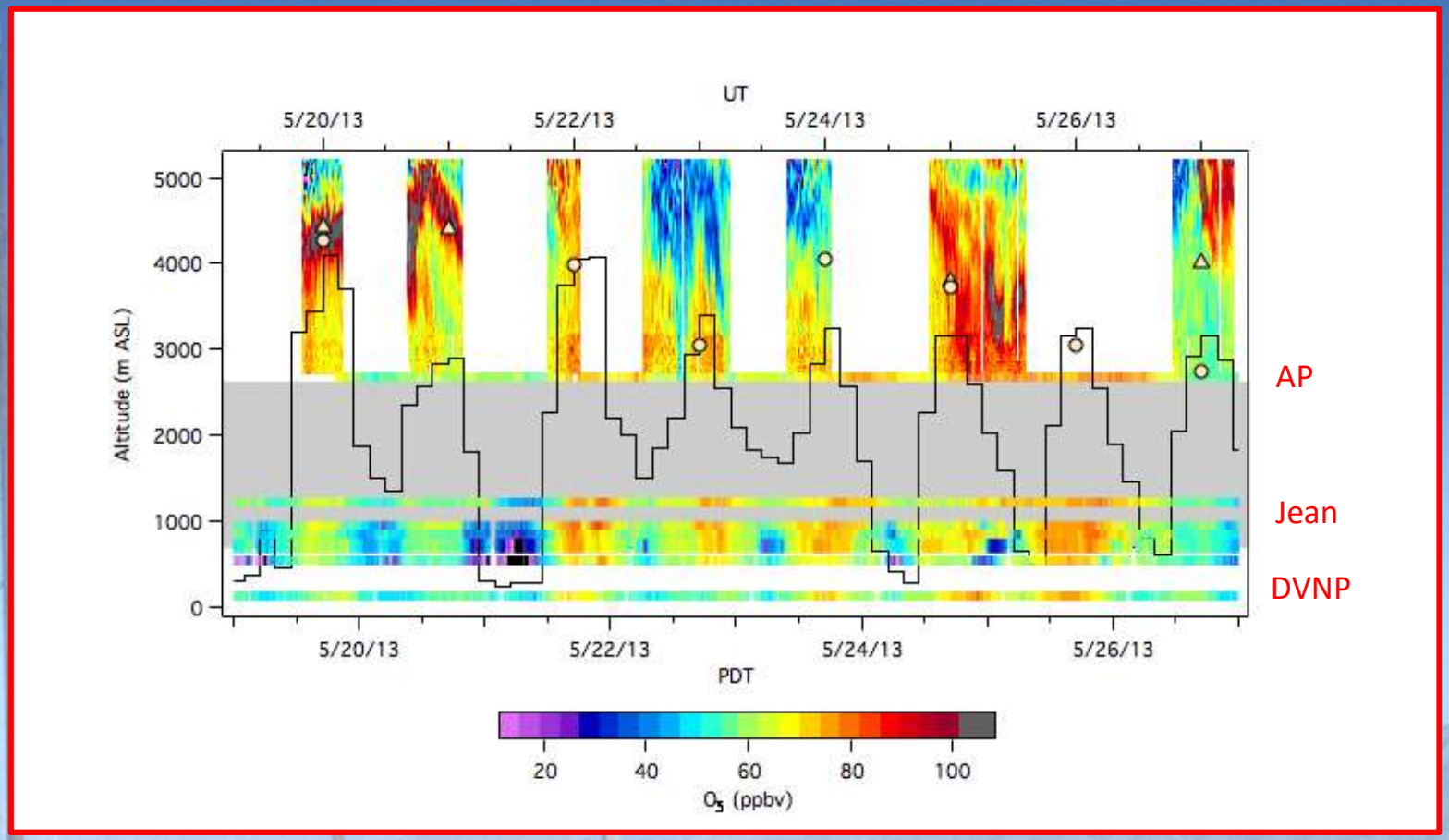
Synoptic Background (May 19-26, 2013)

GOES-WEST 4 km WV images (Owen Cooper)



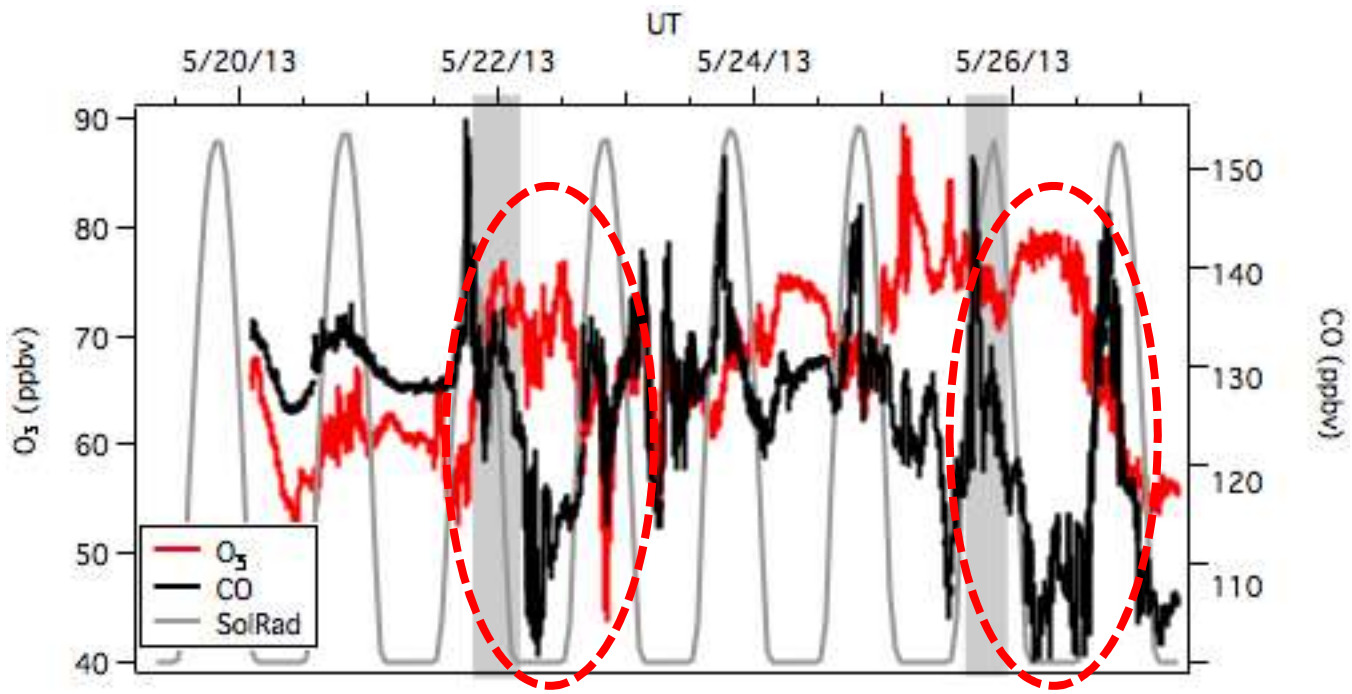
Dry UT/LS air above Angel Peak

TOPAZ Lidar profiles (May 19-26)



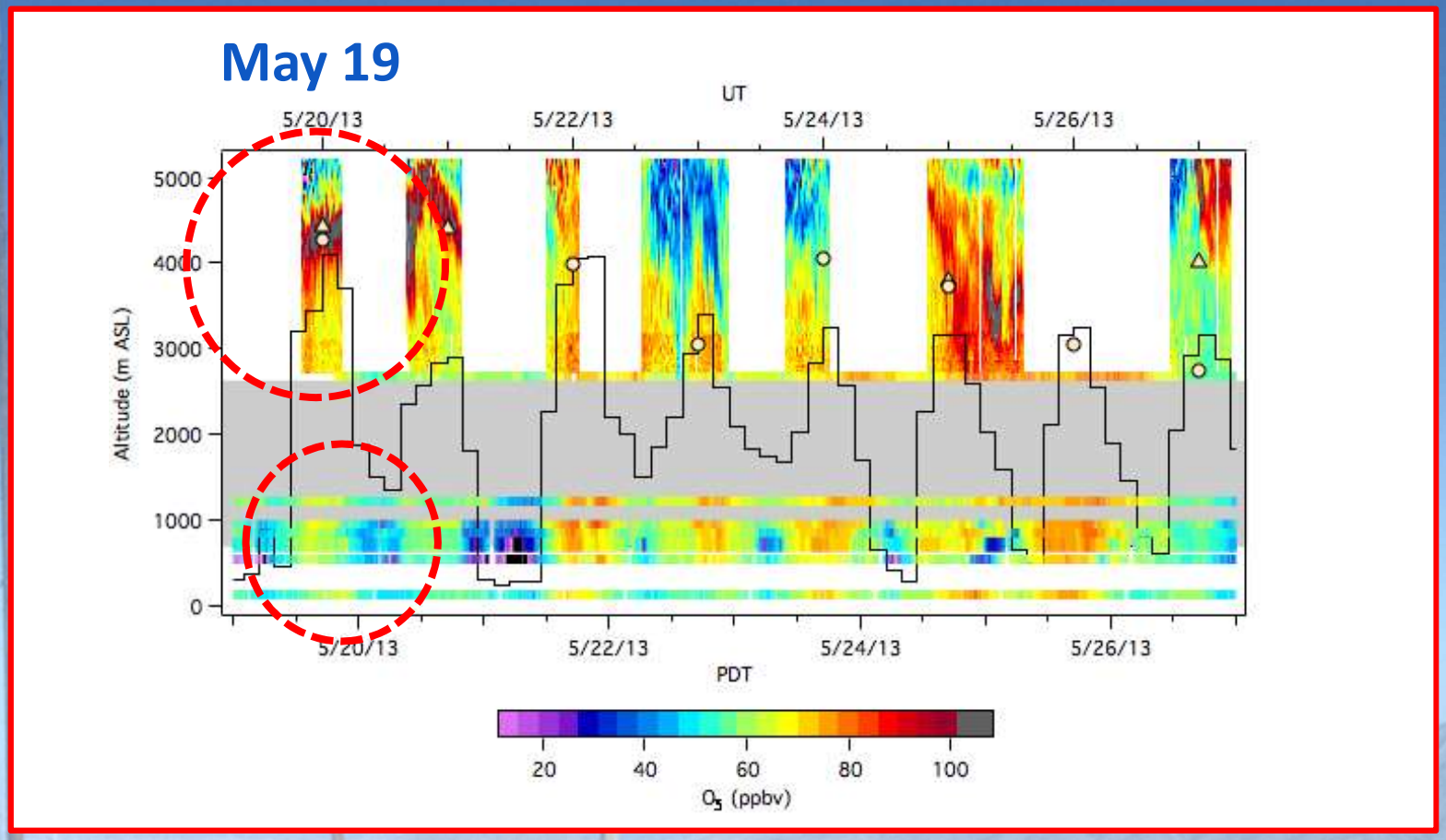
Some O_3 reached the Las Vegas Valley *and* Death Valley

Angel Peak surface measurements



High O_3 at night correlated with low CO (STT) and dry air

TOPAZ Lidar profiles (May 19-26)

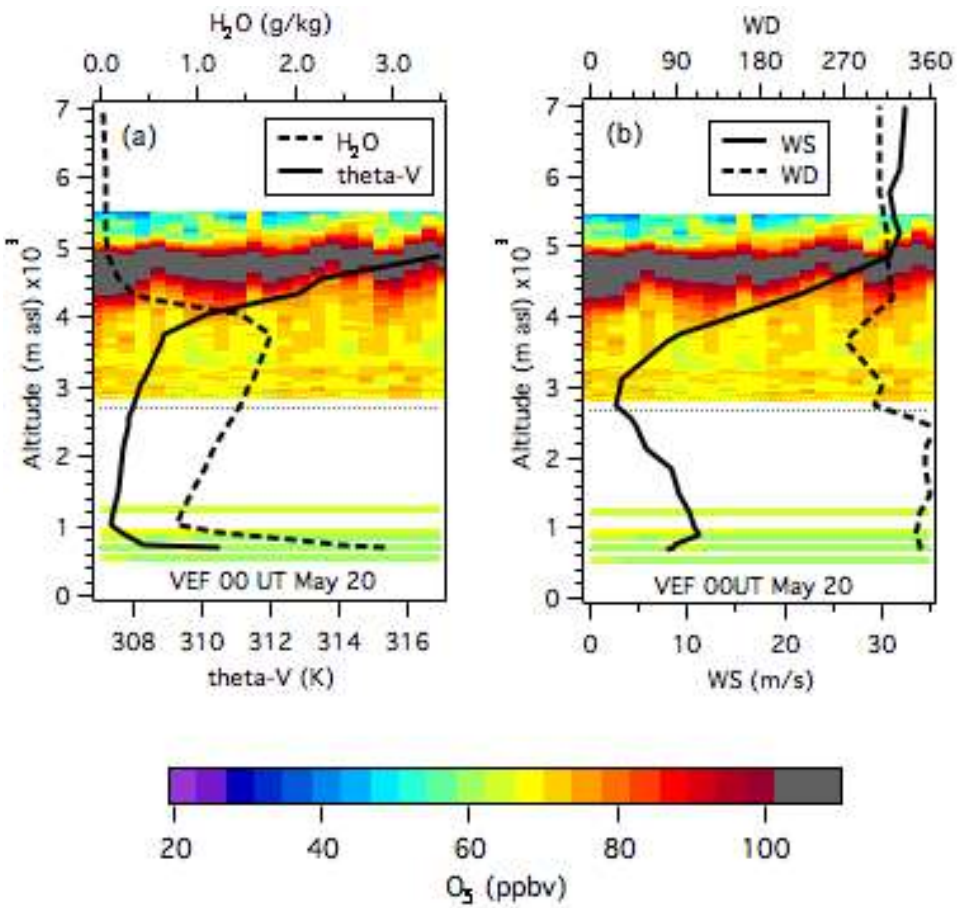


1. Modest entrainment of ozone from aloft

Day 1: May 19, 2013

Stratospheric intrusion

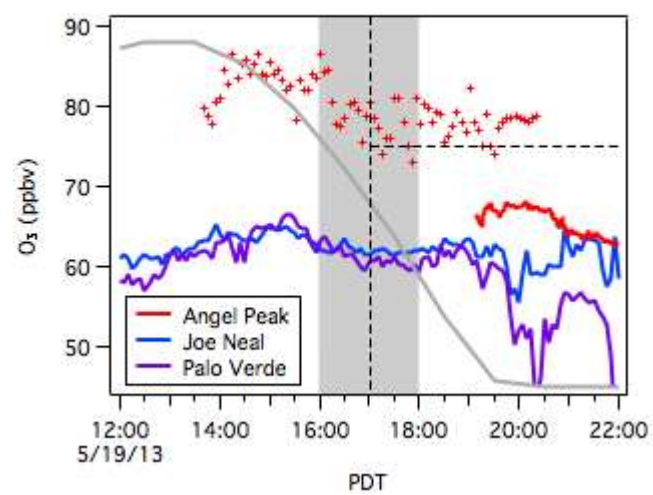
TOPAZ ozone and VEF sounding



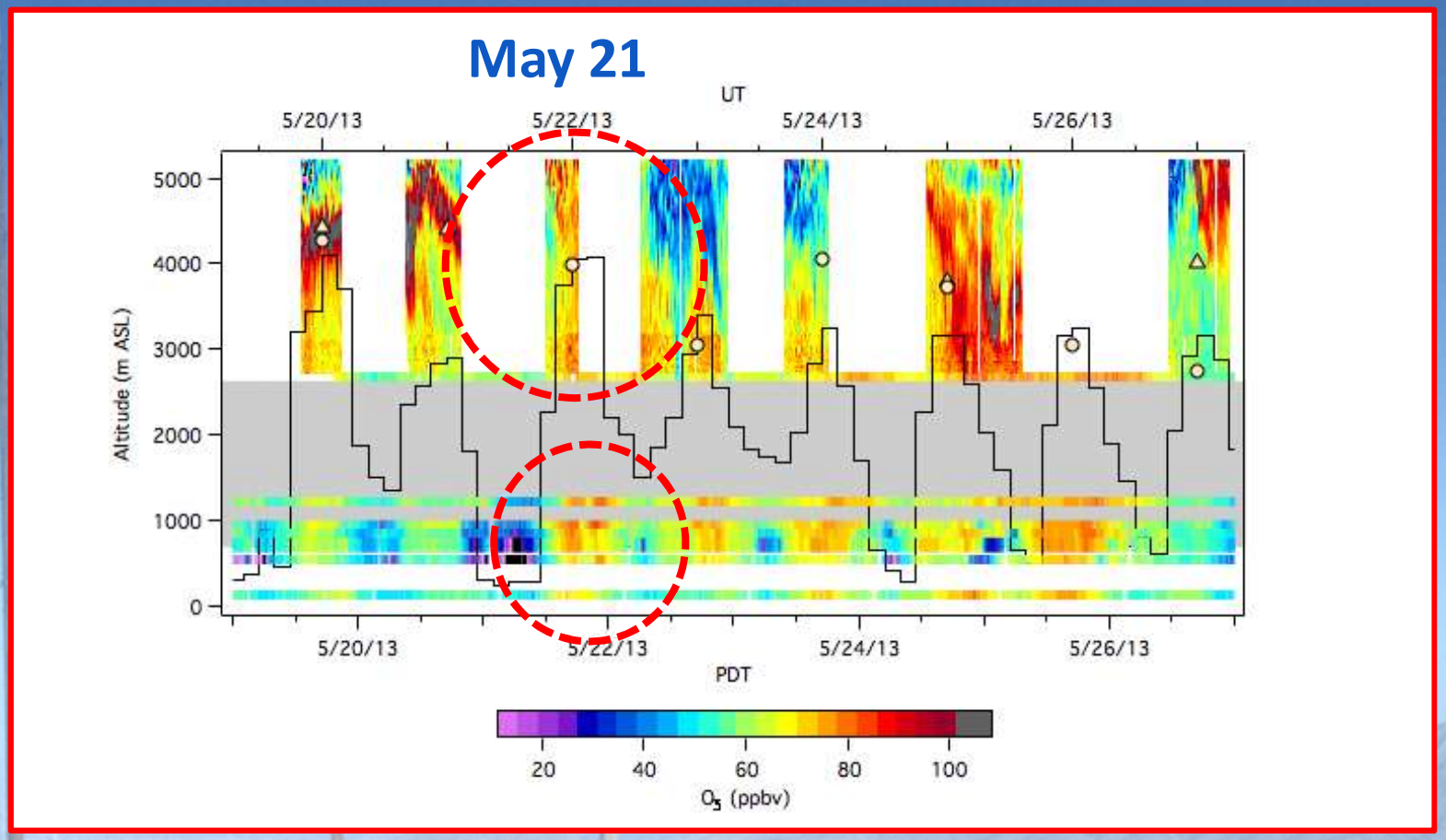
Stable boundary layer

Shear-induced entrainment into upper PBL

No surface O_3 enhancement



TOPAZ Lidar profiles (May 19-26)



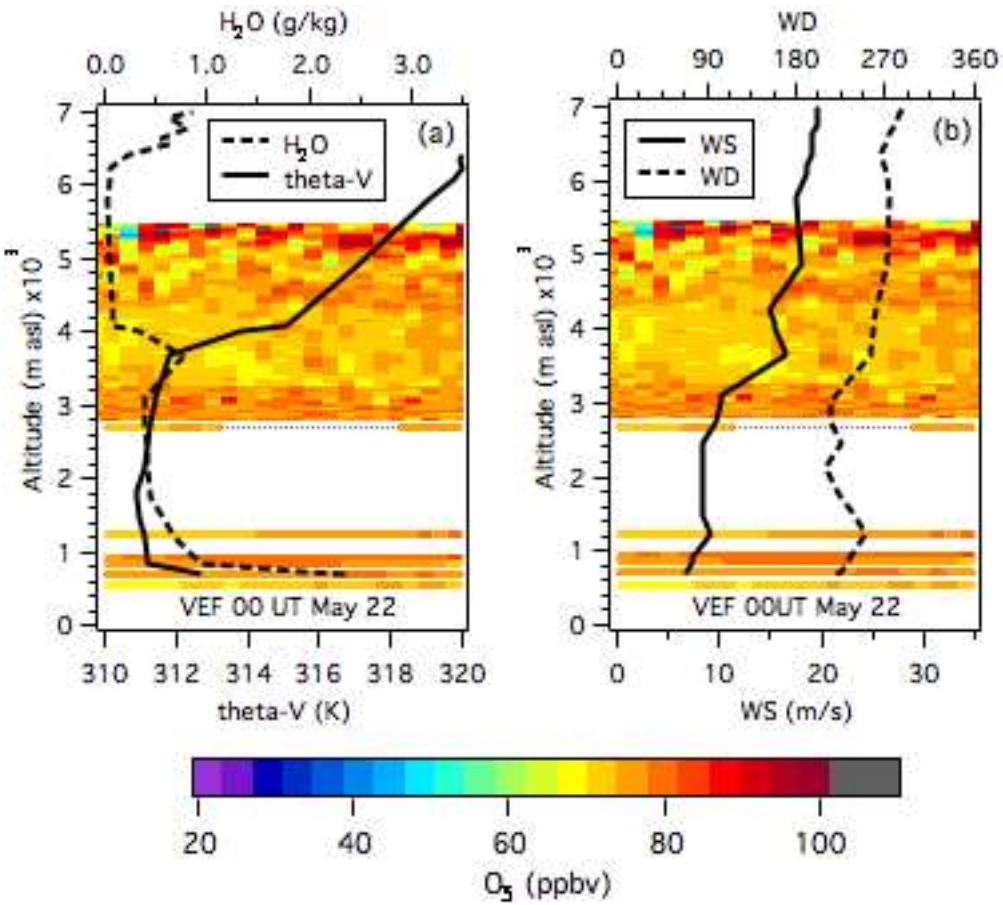
2. Strong entrainment of ozone from aloft

2008 (*2015*) NAAQS exceeded at 1(9*)* of 11 monitors

Day 3: May 21, 2013

Stratospheric intrusion/Asian pollution

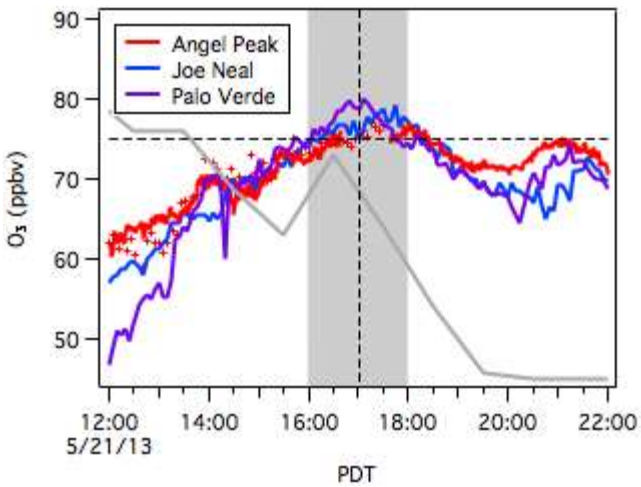
TOPAZ ozone and VEF sounding



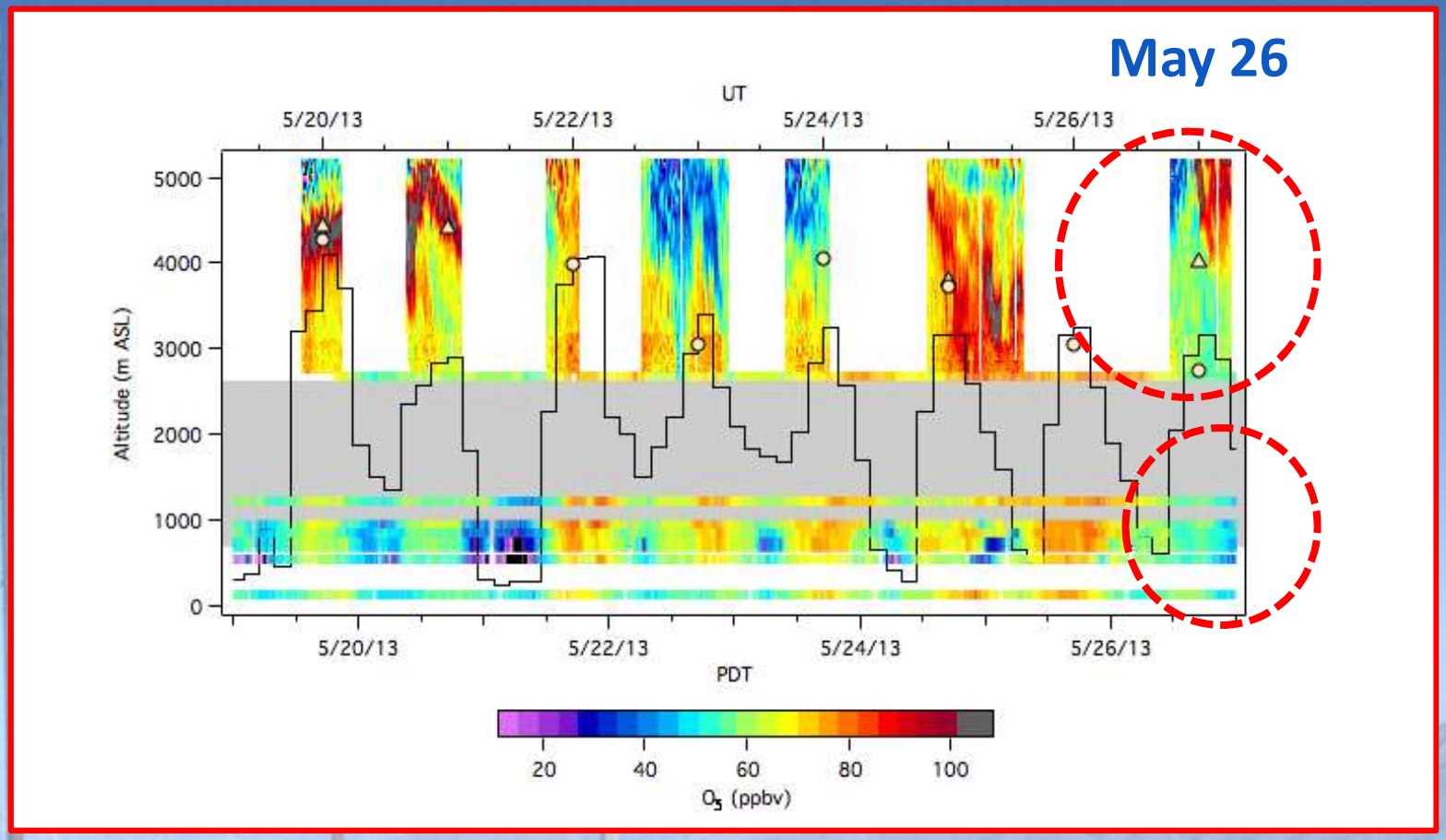
CBL well-mixed up to 4.5 km asl

High O_3 layer entrained

High surface O_3 in LVV with 2008 NAAQS exceeded at Jean



TOPAZ Lidar profiles (May 19-26)

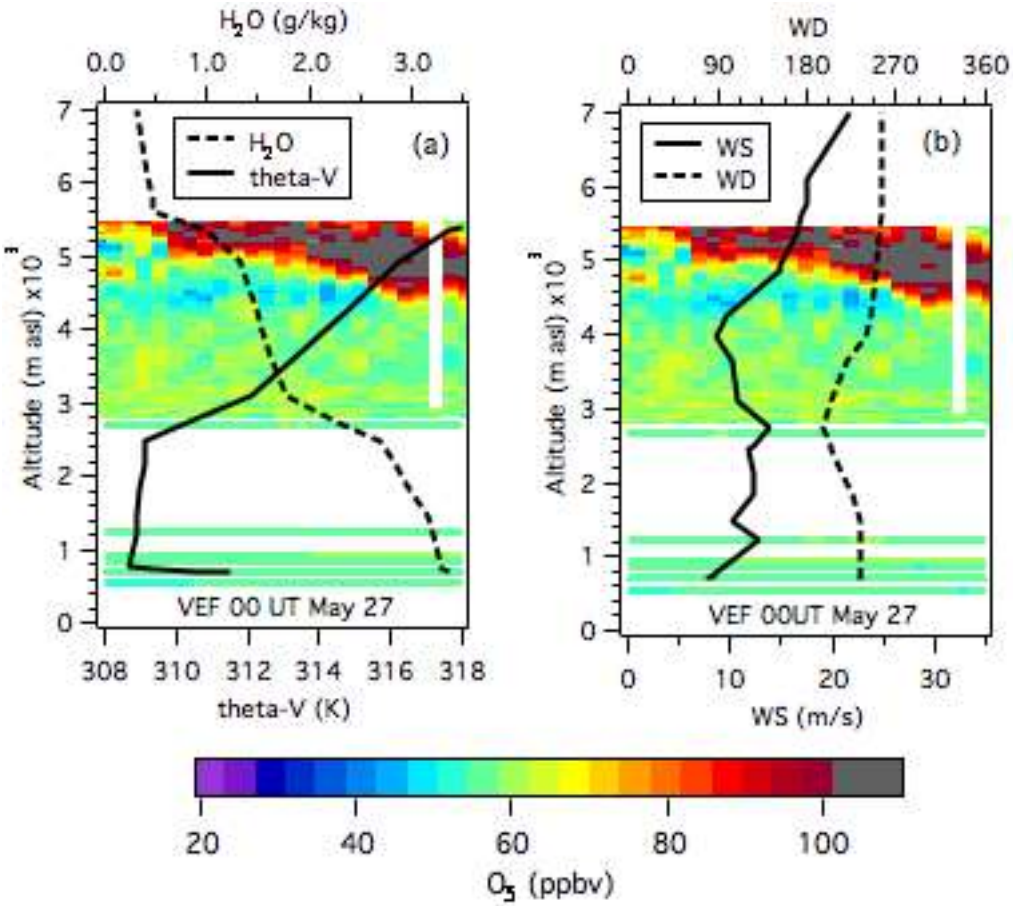


3. No entrainment of ozone from aloft

Day 8: May 26, 2013

Asian pollution

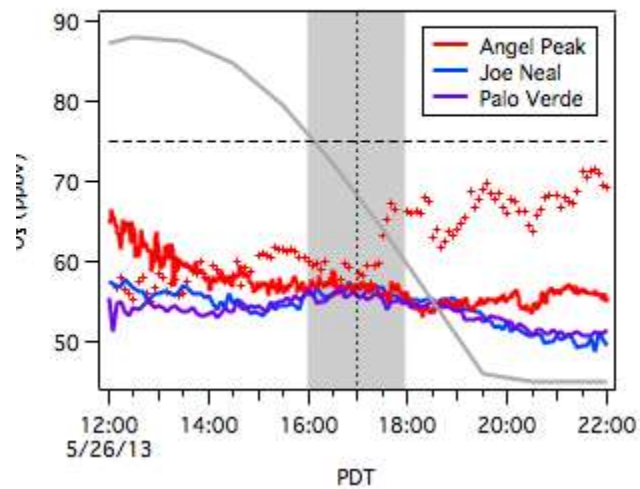
TOPAZ ozone and VEF sounding



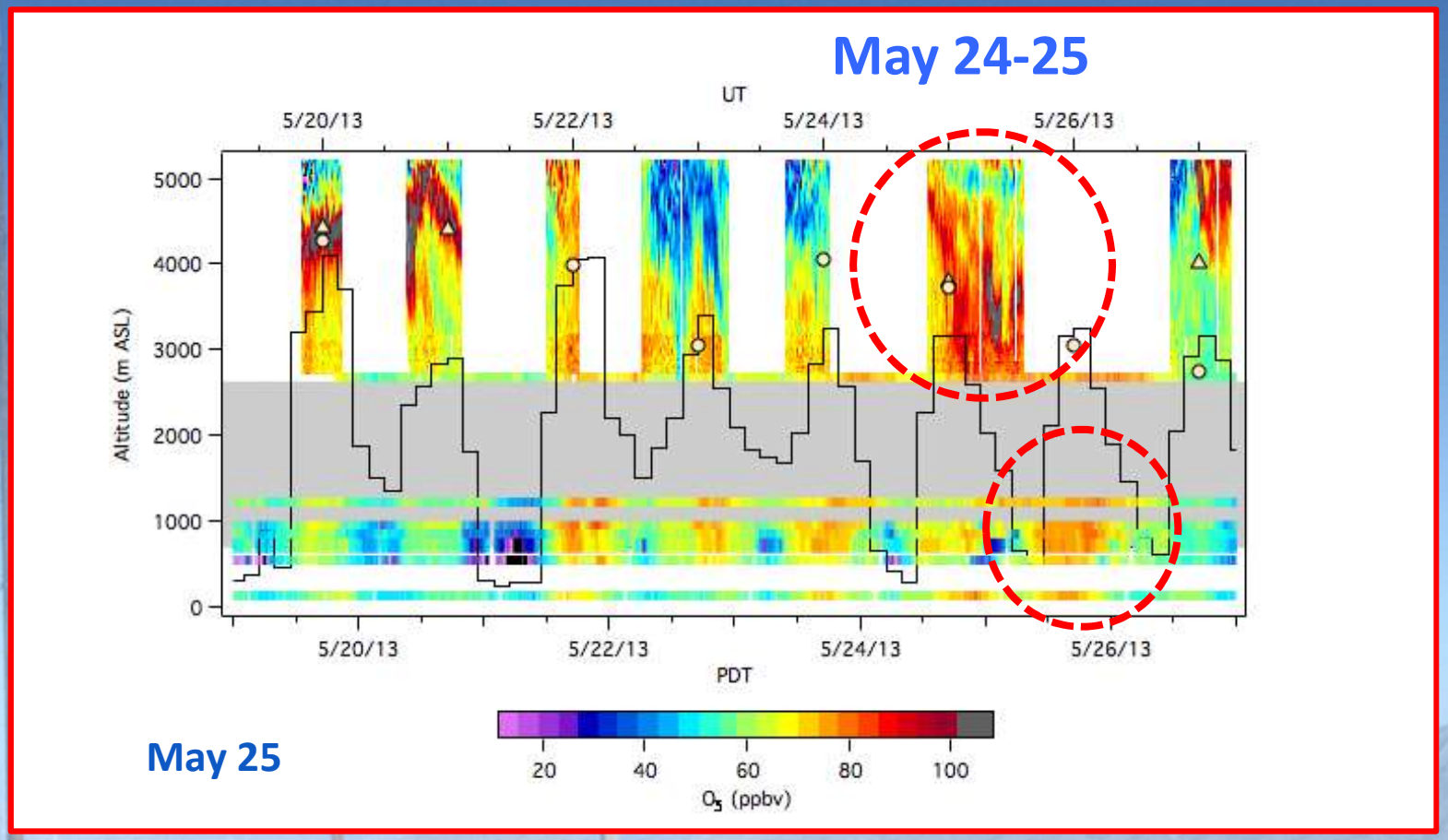
CBL well-mixed up to 3 km asl

No entrainment

No surface O_3 enhancement



TOPAZ Lidar profiles (May 19-26)

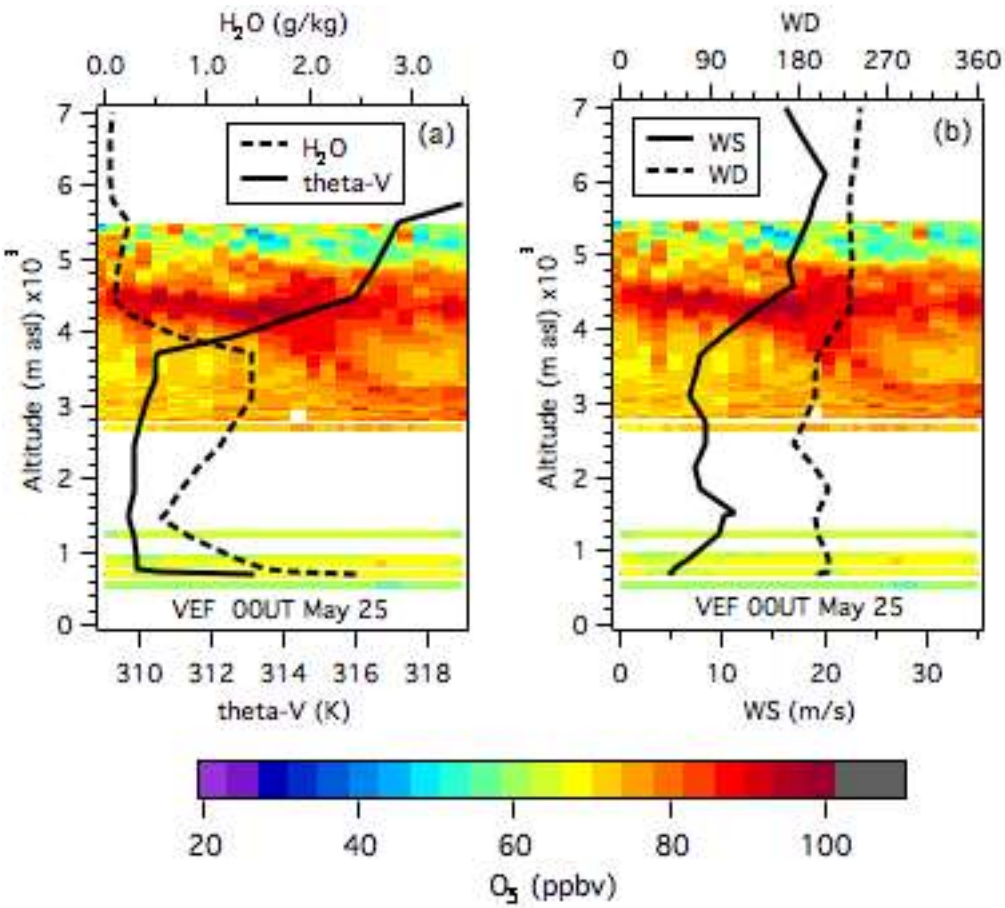


4. Strong entrainment of ozone from aloft

2008 (*2015*) NAAQS exceeded at 4(*9*) of 11 monitors

Day 6: May 24, 2013

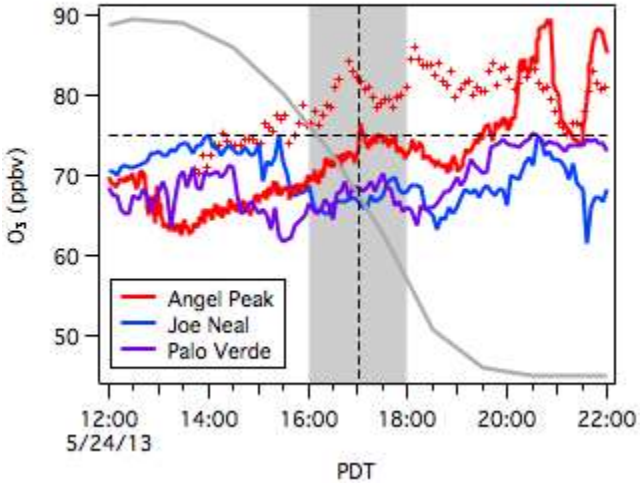
TOPAZ ozone and VEF sounding



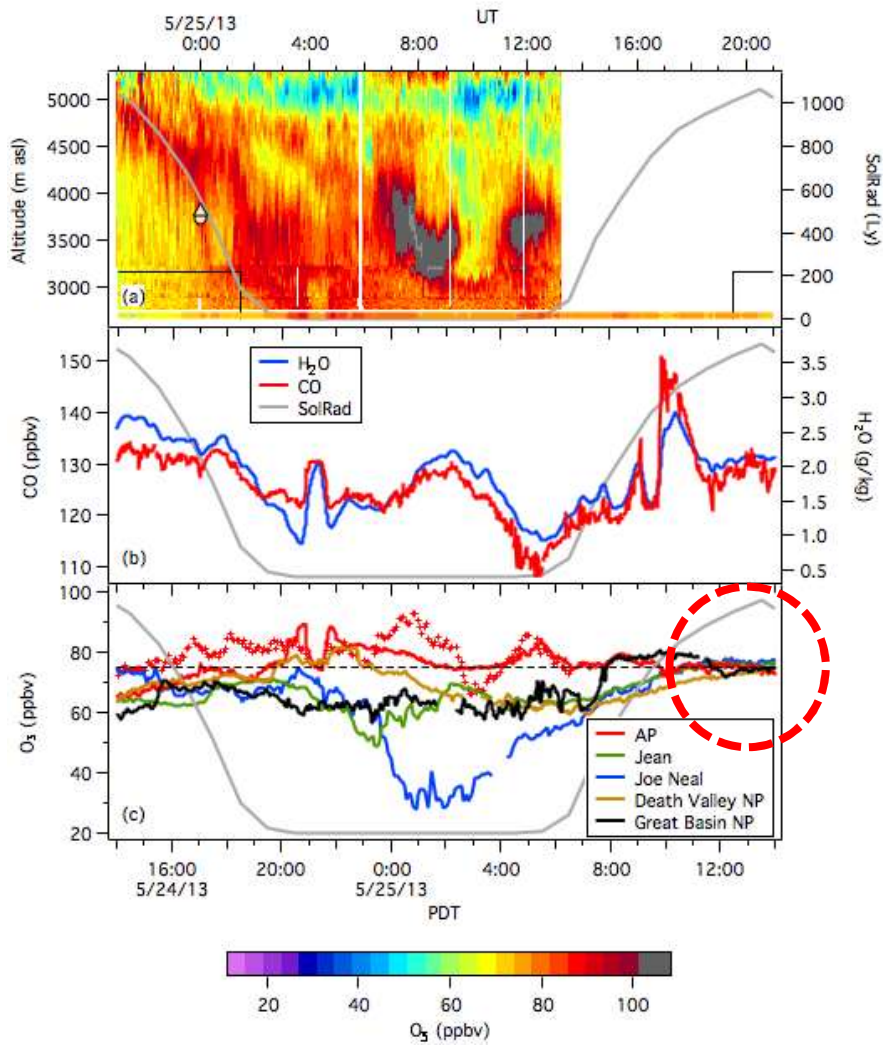
STT

Deep well-mixed CBL beginning to subside when high O_3 appears in the afternoon.

O_3 descends to Angel Peak during the evening as the CBL subsides.



May 24-25, 2013

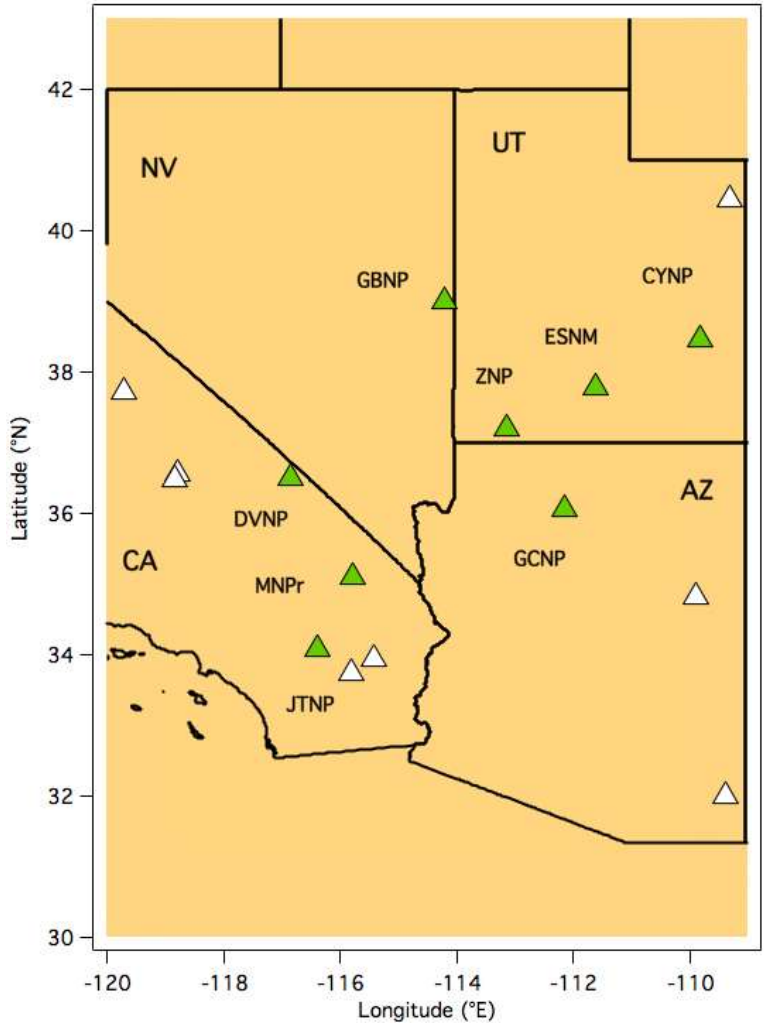


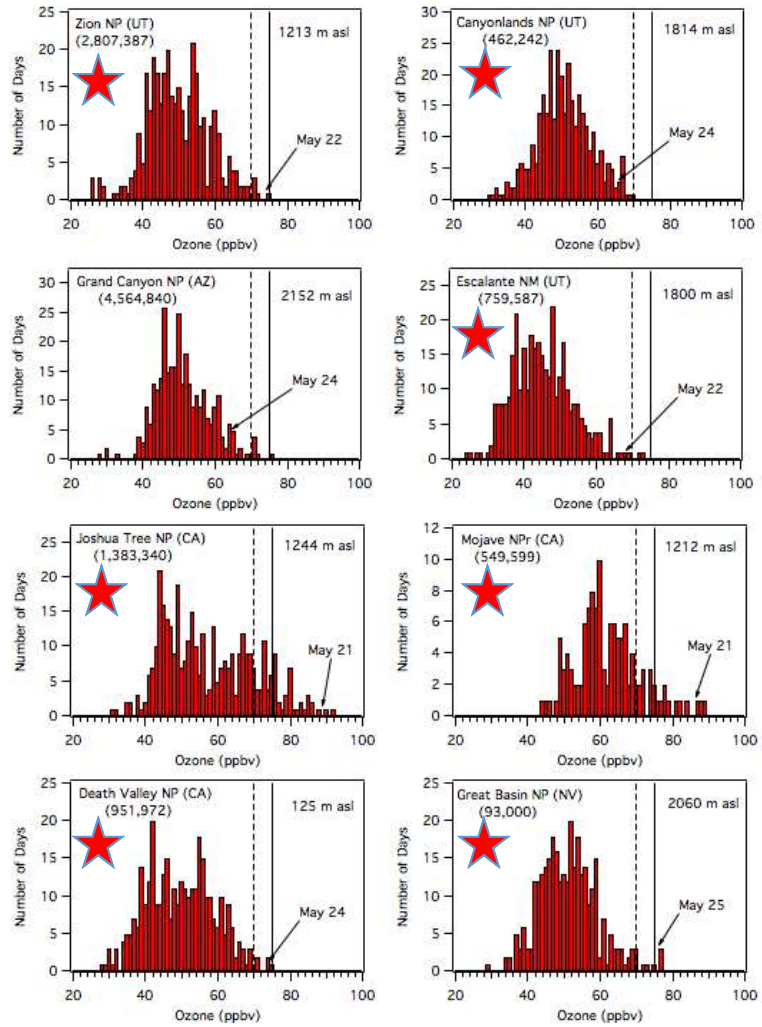
Direct descent of high O_3 to the summit of Angel Peak during night

CO and H_2O tightly correlated, but anticorrelated with O_3 during night.

O_3 in Clark County and nearby National Parks converges at 75±2 ppbv by noon on May 25.

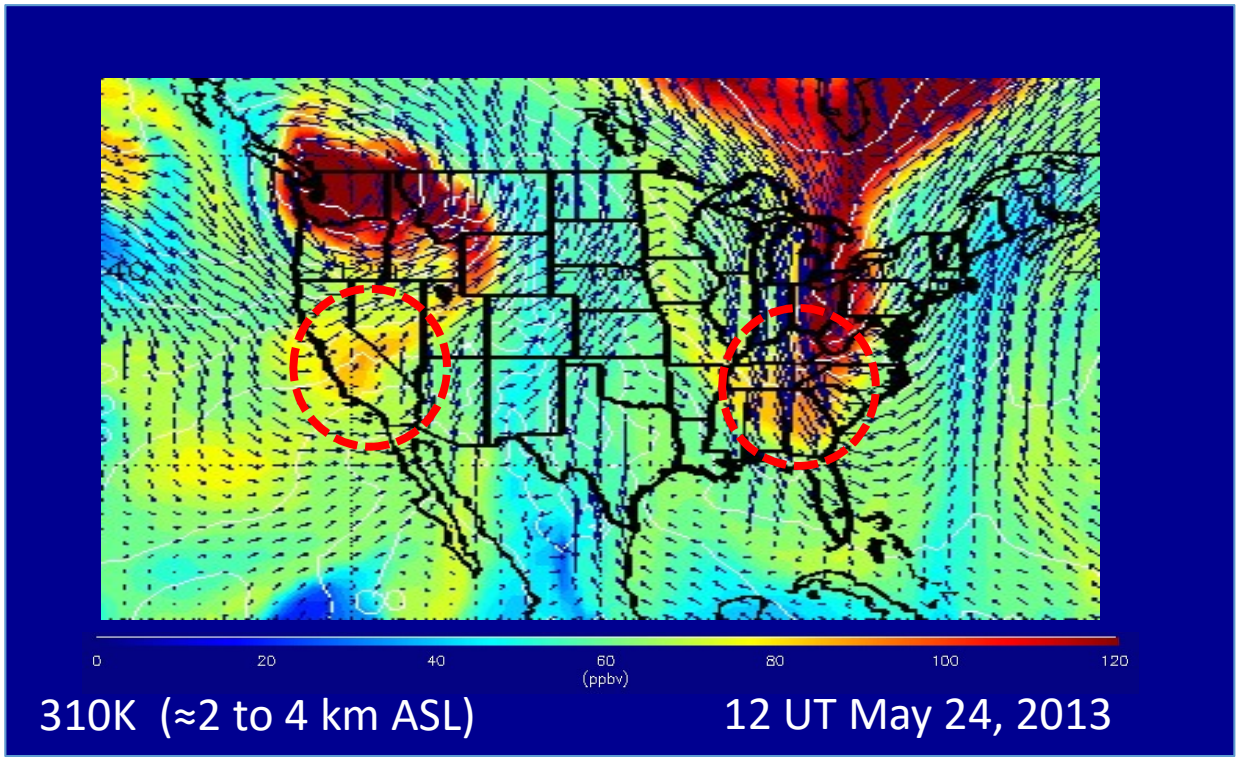
Impact on National Parks





★ 1 of 3 highest ozone days in 2013 between May 19 and 26

Impact on continental U.S.

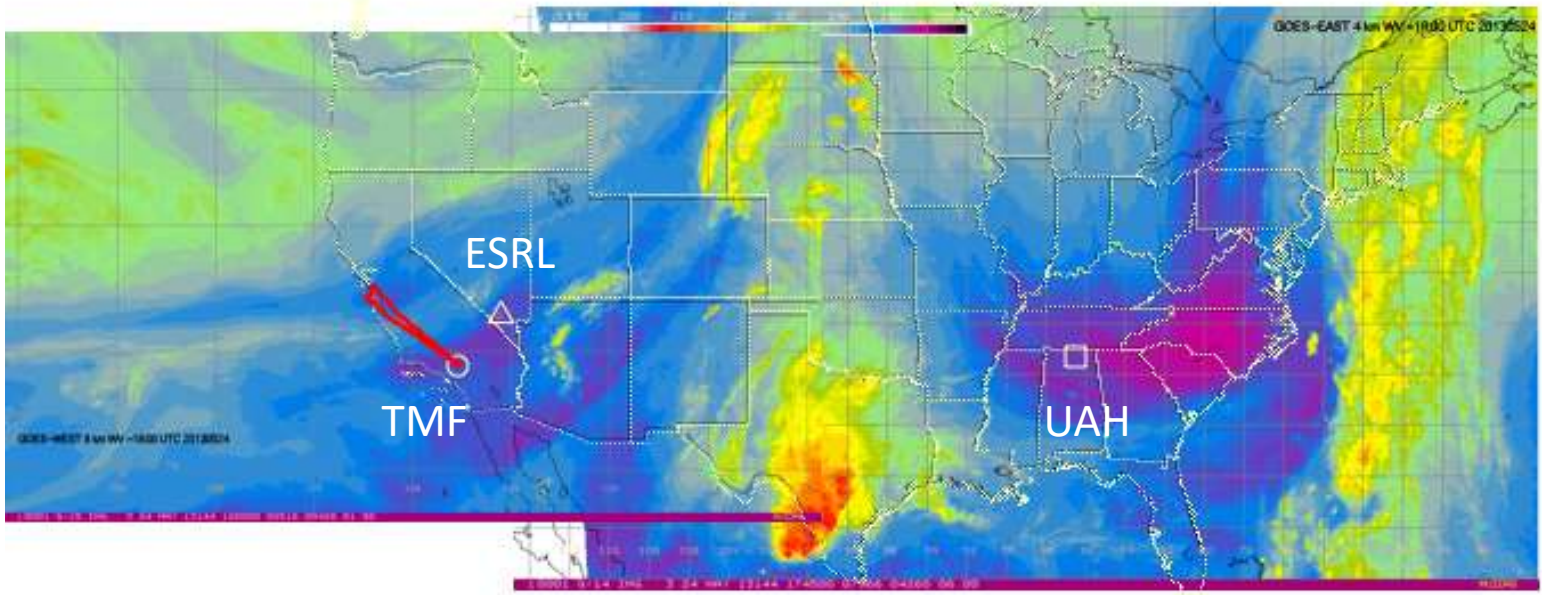


Brad Pierce (NOAA/NESDIS)

***TWO* tropopause folds above the eastern and western U.S.**

Dry slots above TOLNet stations in WV imagery

GOES-W/E Composite 4 km WV 1800 UT May 24, 2013



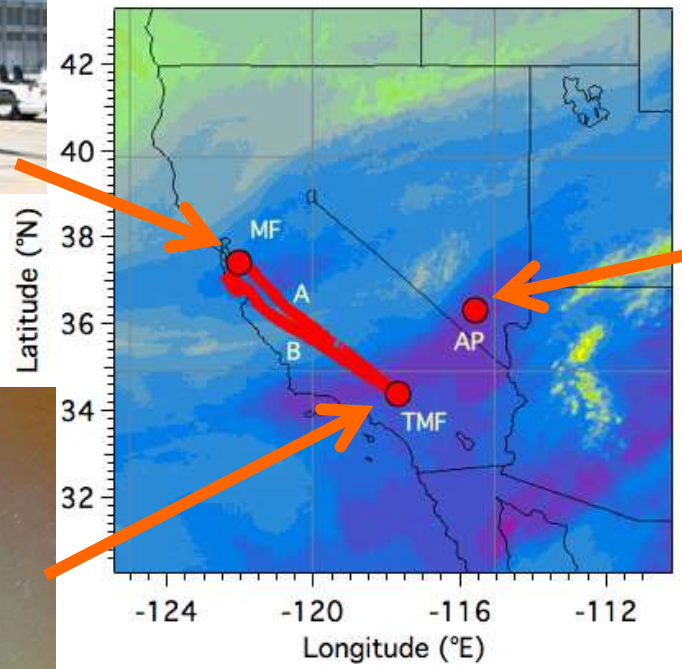
Owen Cooper (NOAA/CIRES)

Western U.S. measurements

In situ O_3, CO_2, CH_4, H_2O

lidar, sonde, in situ O_3

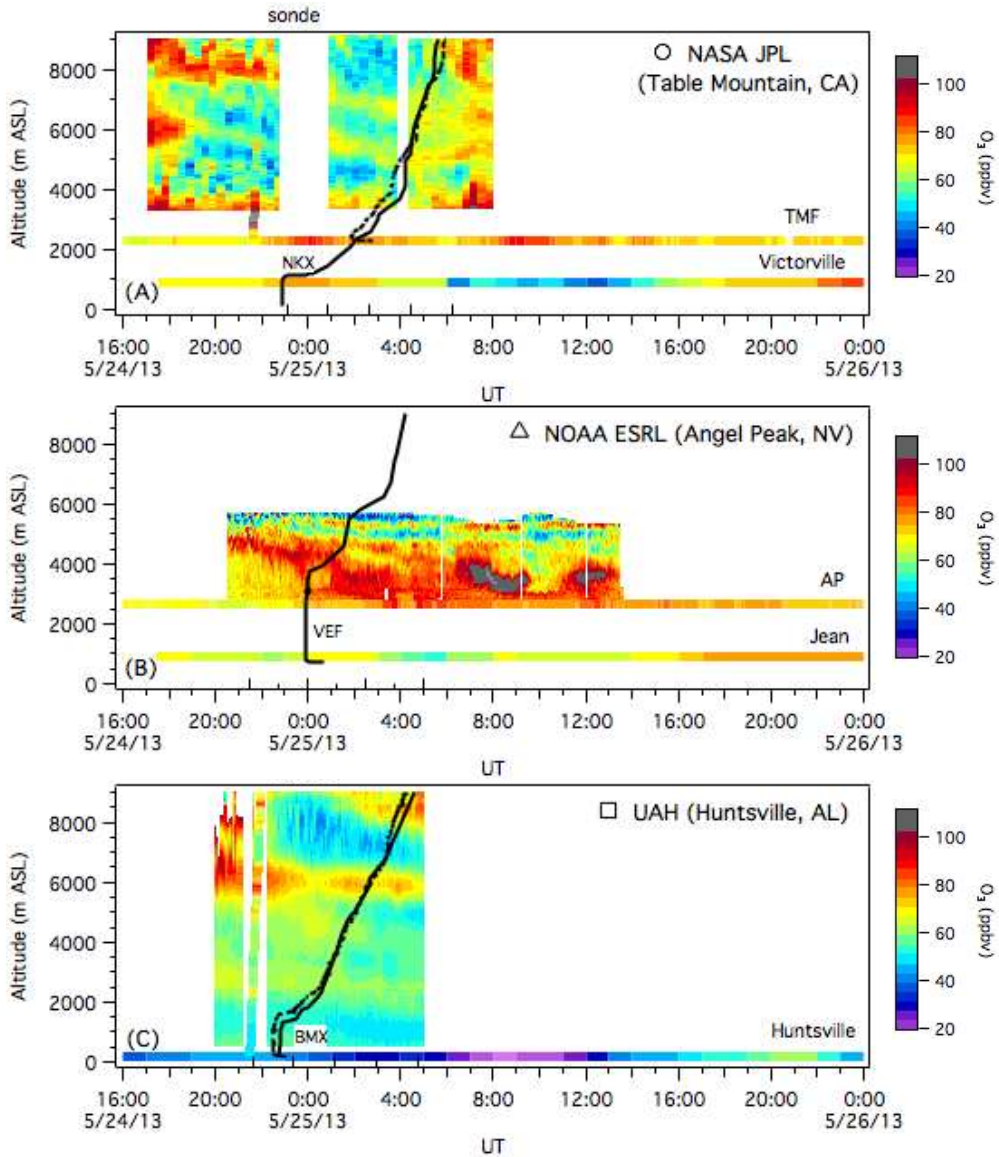
GOES-WEST WV distribution at 18UT (11PDT)



Owen Cooper (NOAA/CIRES)

lidar, in situ O_3, CO, H_2O

Simultaneous measurements by 3 TOLNet lidars



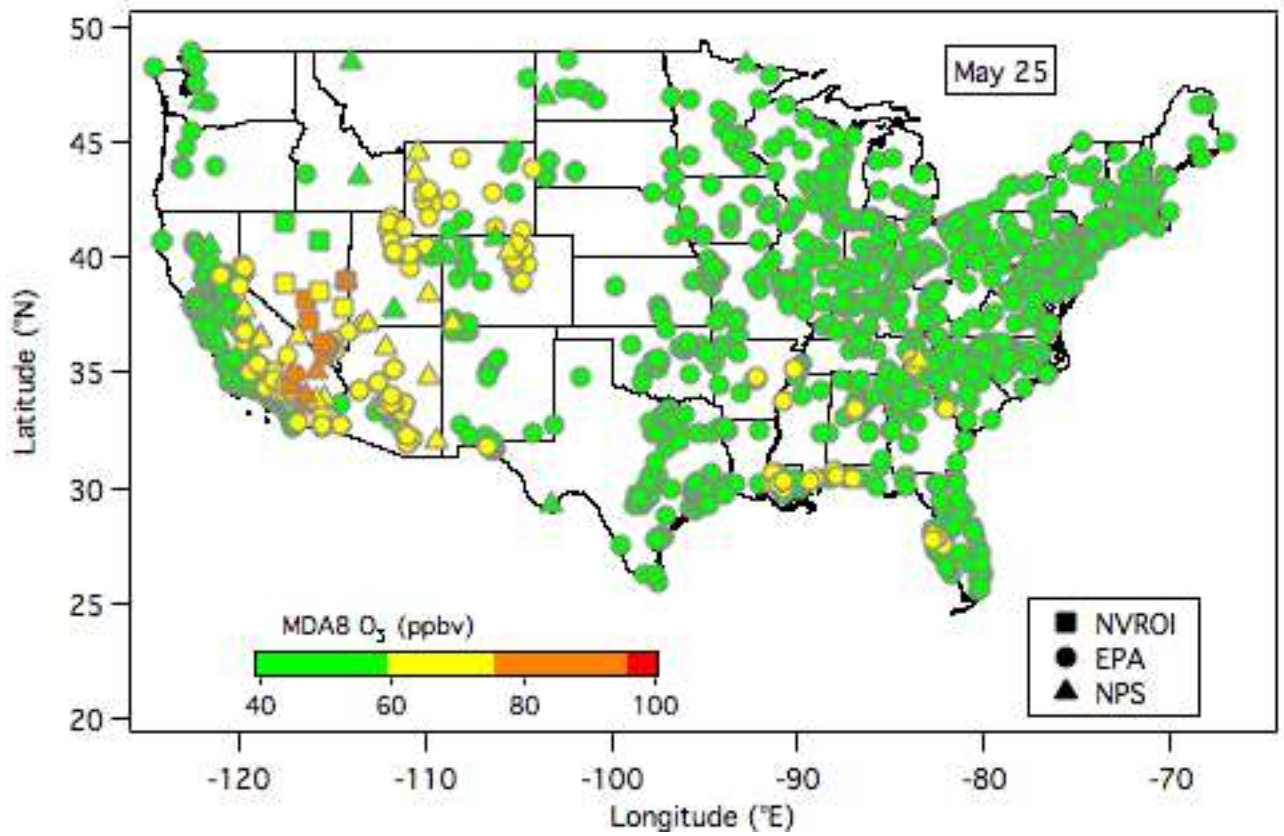
Deep mixed layers entrain O_3 in the Mojave Desert

Shallow, tightly capped PBL limits entrainment along coast

Deep mixed layers entrain O_3 in Nevada and mix it to lower elevations the next day

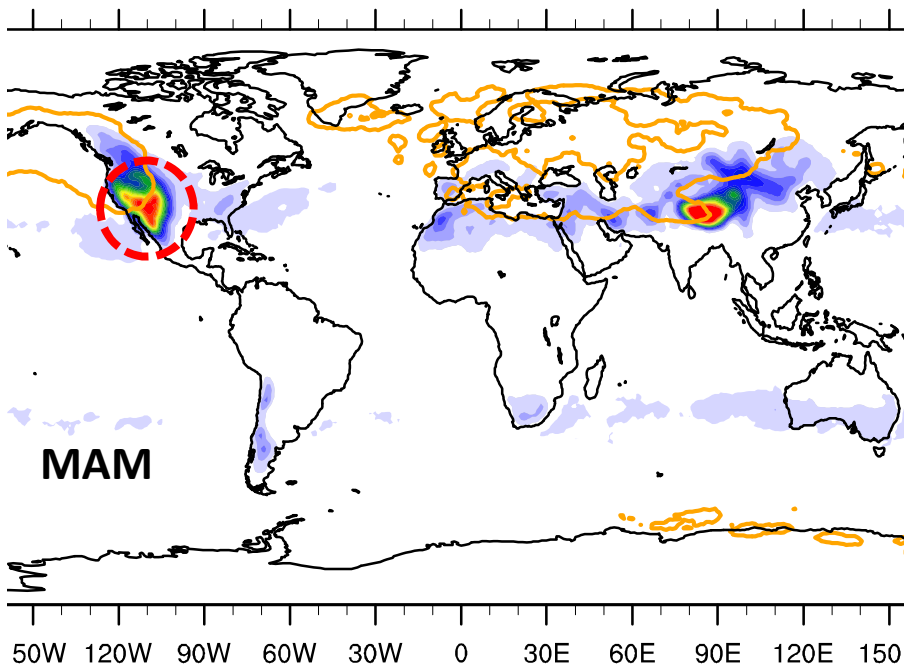
Shallow, tightly capped PBL limits entrainment in Alabama

Surface ozone on May 25, 2013



High surface O_3 across SW and IMW (and Gulf Coast)

Why the Southwest?

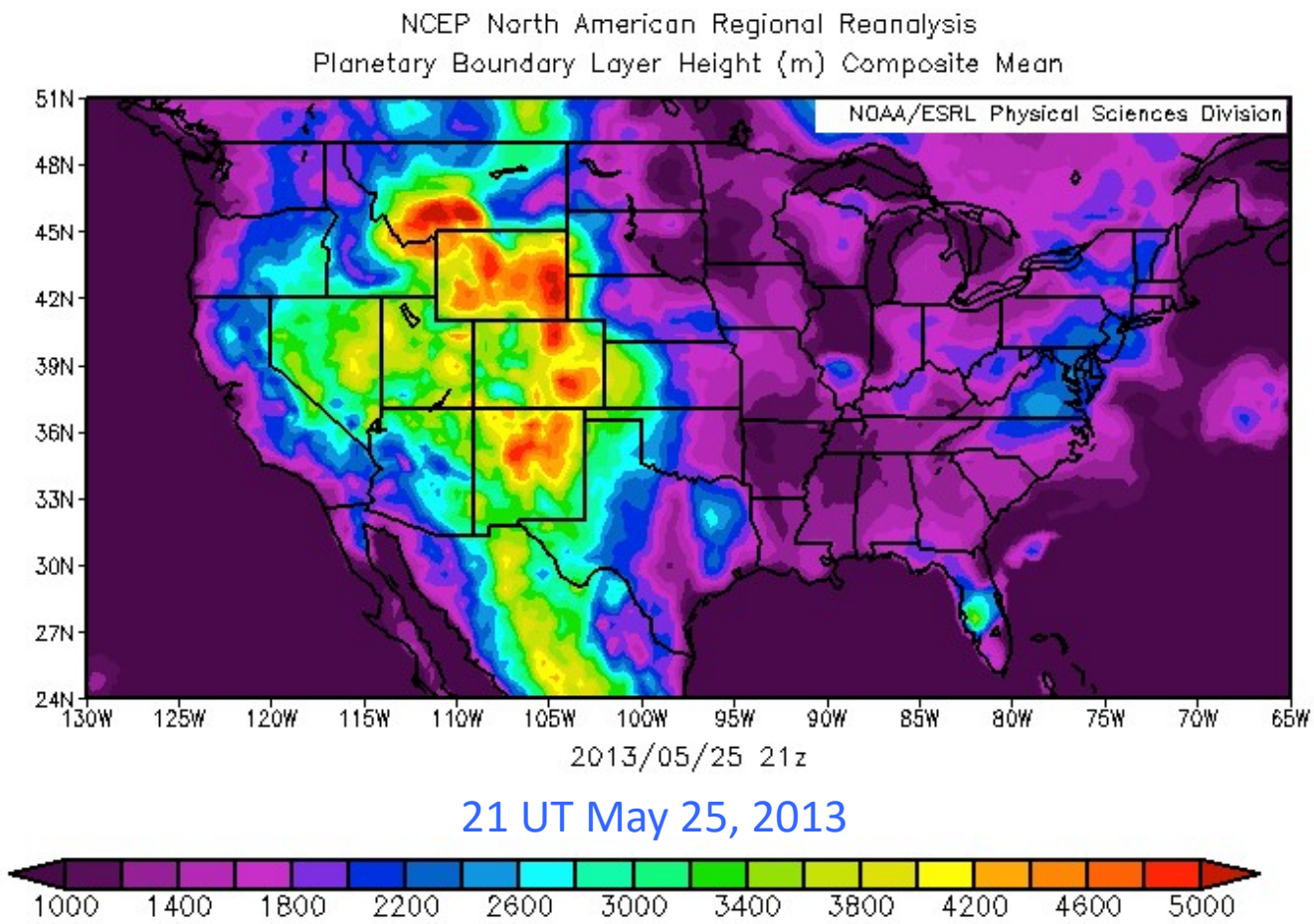


A global climatology of stratosphere–troposphere exchange using the ERA-Interim data set from 1979 to 2011

B. Škerlak, M. Sprenger, and H. Wernli ACP, 14, 913–937, 2014

SW U.S. is one of global hotspots for *deep* STT

Planetary Boundary Layer



21 UT May 25, 2013

Deeper springtime Boundary Layers over the SW and IMW

Summary and Conclusions

- Tropopause folds are common events
  (*usually associated with cyclogenesis*)
- High springtime ozone in SW primarily due to STT
  (*Asian pollution is secondary*)
- SW hotspot because of deep intrusions *and* deep CBLs
  (*Elevation is secondary*)
- STT-related exceedances will increase with new NAAQS
  (*STT-driven exceedances in SW may not be "exceptional" in May-June*)

Acknowledgements

NOAA ESRL CSD: Raul Alvarez , Jerome Brioude, Owen Cooper, John Holloway, Richard Marchbanks, Scott Sandberg, Christoph Senff , Ann Weickmann, Eric Williams

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NOAA/NESDIS/CIMMS: Brad Pierce

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U. of Nevada Reno (NVROI):Rebecca Fine, Mae Gustin

NASA Ames: Emma Yates , Laura Iraci

TOLNet

NASA JPL/TMF: Guillaume Kirgis, Thierry Leblanc

U. of Alabama, Huntsville: Shi Kuang, Mike Newchurch

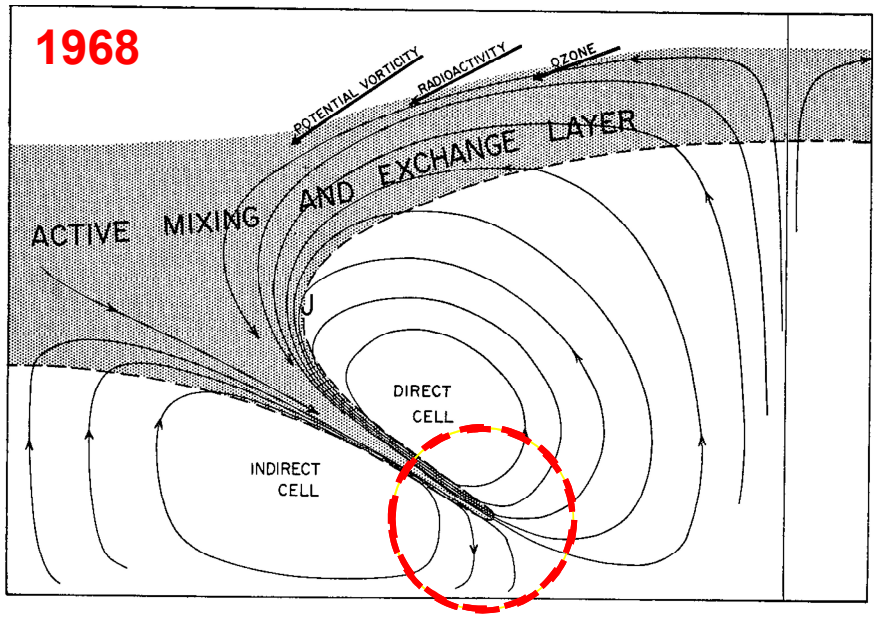
Clark County DAQ: Zheng Li

STOP

Stratosphere-to-Troposphere Transport (STT) by tropopause folding

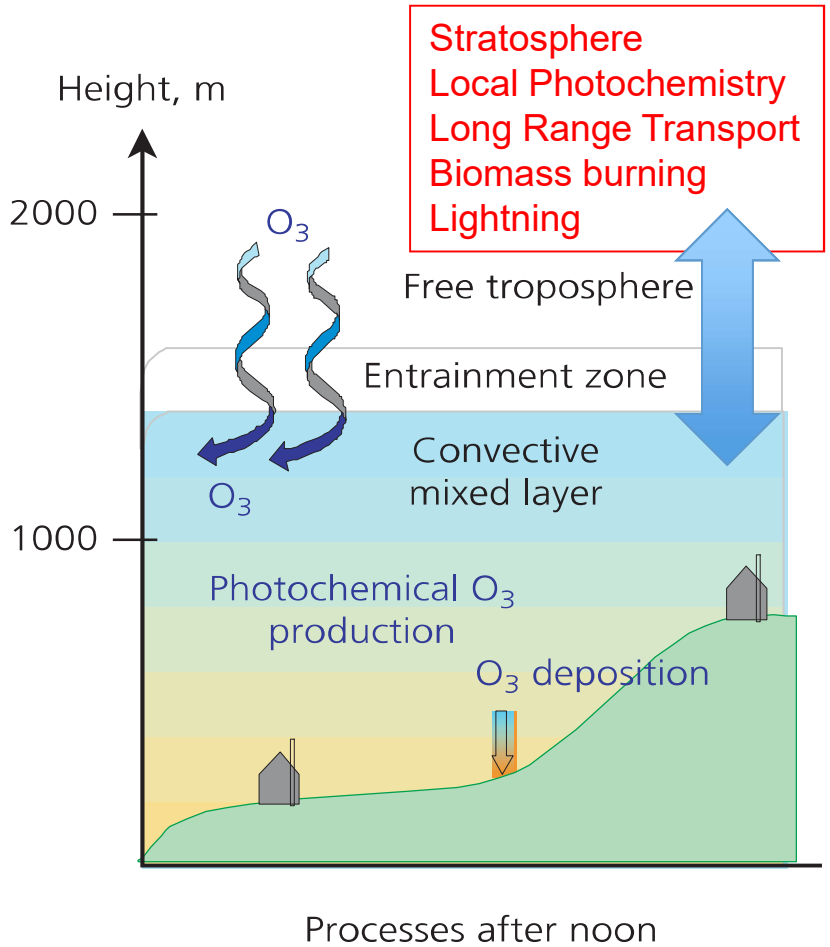
Stratospheric-Tropospheric Exchange Based on Radioactivity, Ozone and Potential Vorticity[1]

EDWIN F. DANIELSEN



Most stratospheric intrusions created by tropopause folding

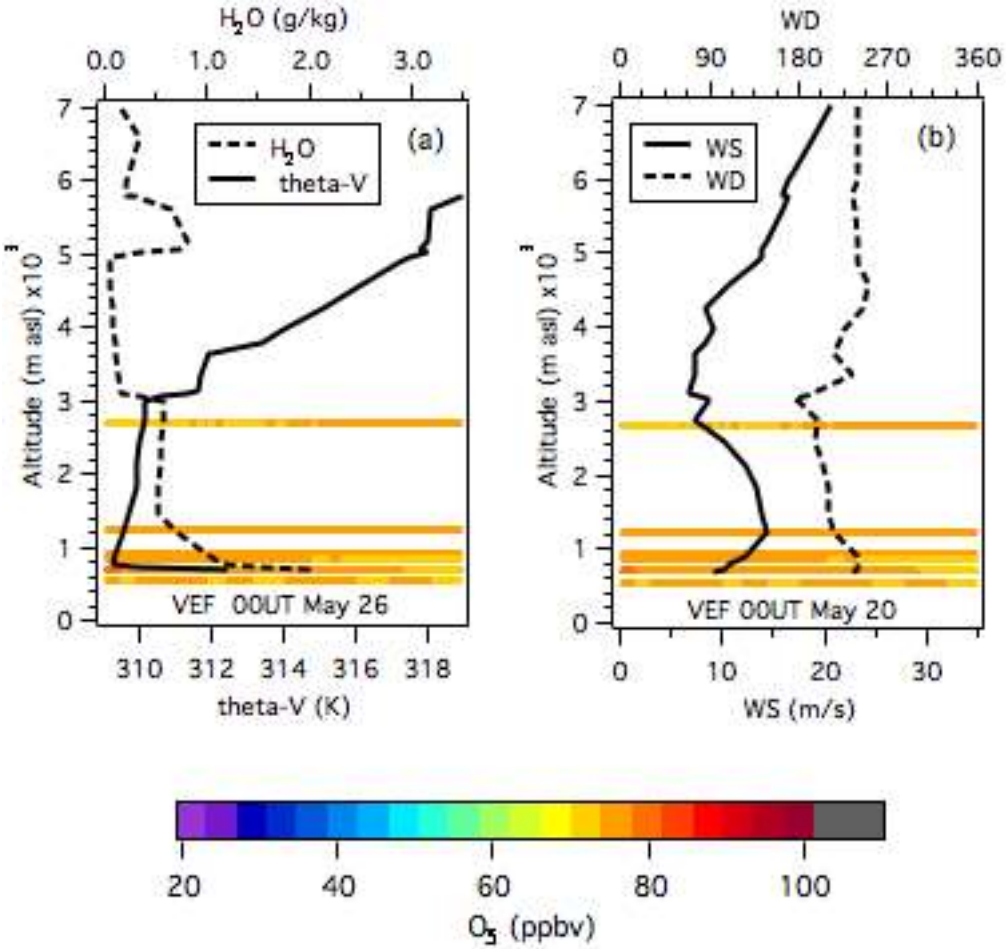
Key uncertainty is coupling between FT and BL



From *The Royal Society*, 2008: Ground-level ozone in the 21st century: future trends, impacts and policy implications

Day 5: May 25, 2013

TOPAZ ozone and VEF sounding

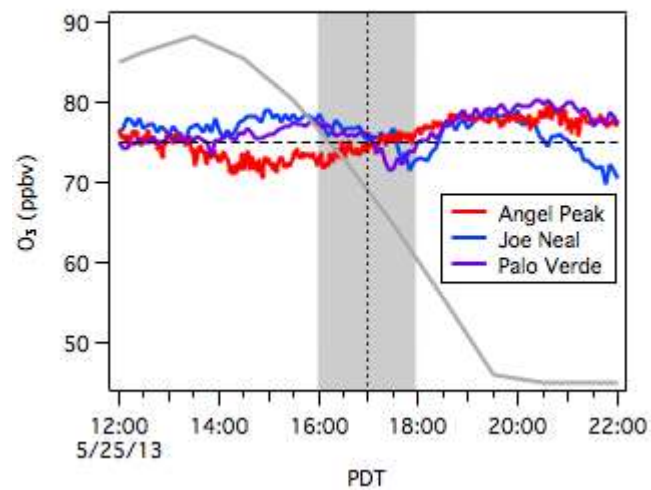


STT

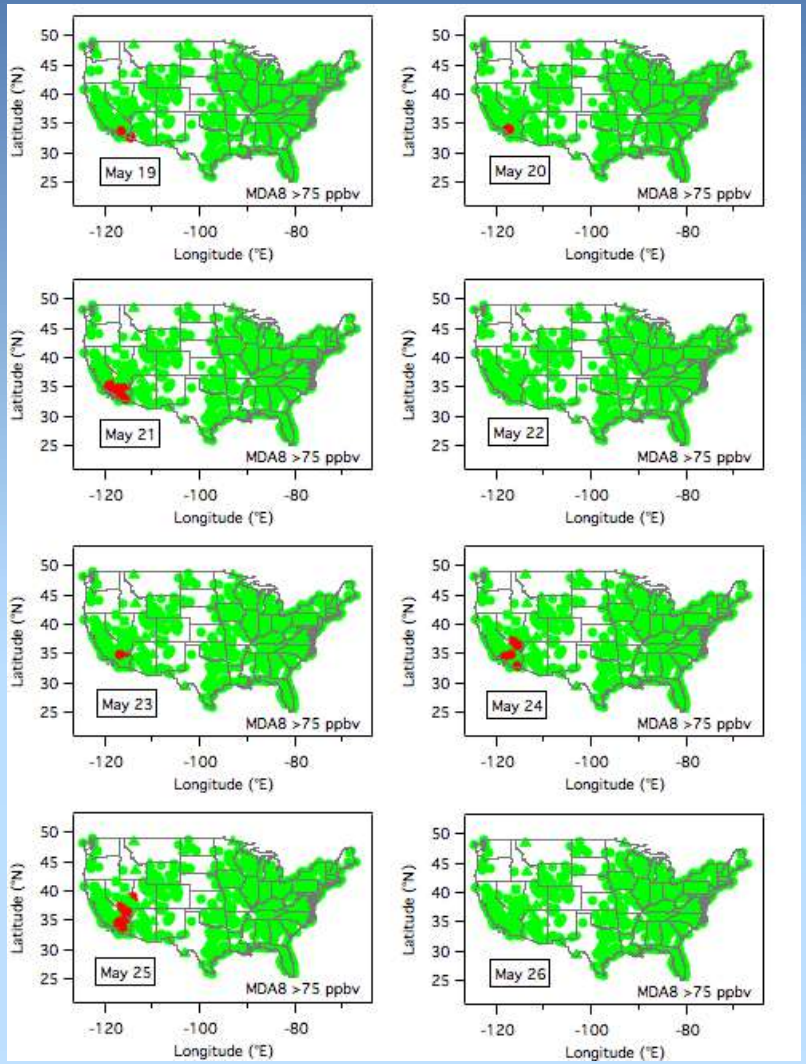
CBL well-mixed until late afternoon

Deep well-mixed CBL beginning to subside by 00 UT (17 PDT).

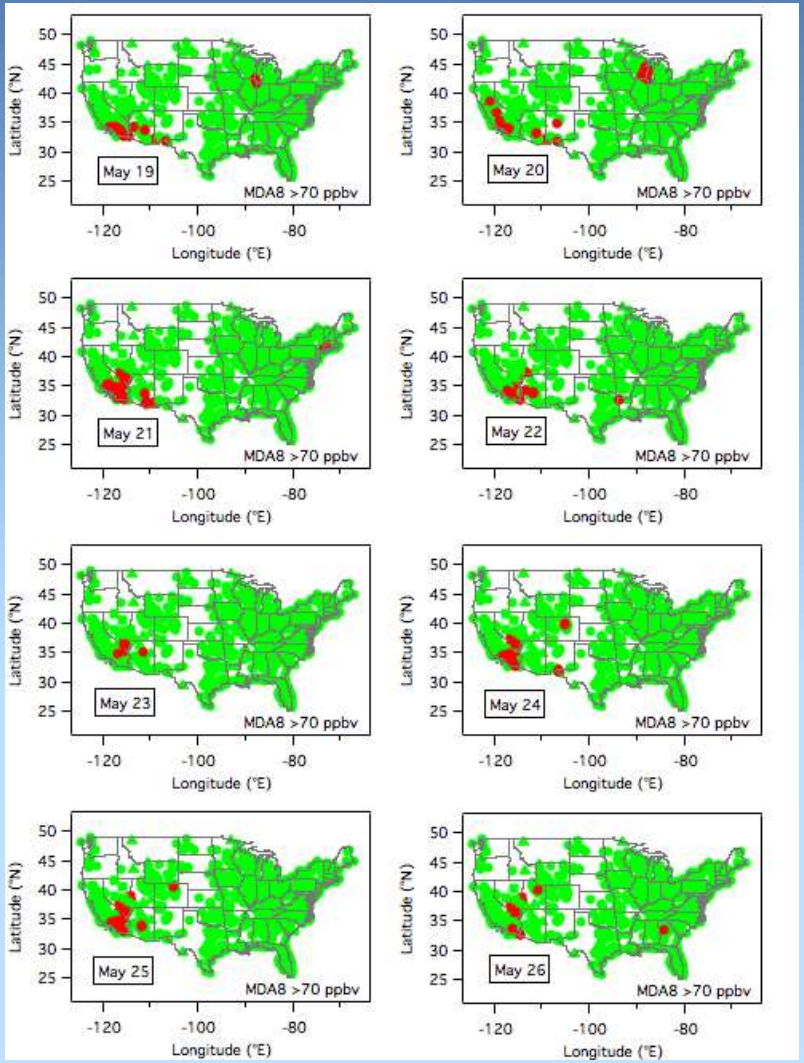
O_3 mixed to surface all day.



Impact on NAAQS compliance

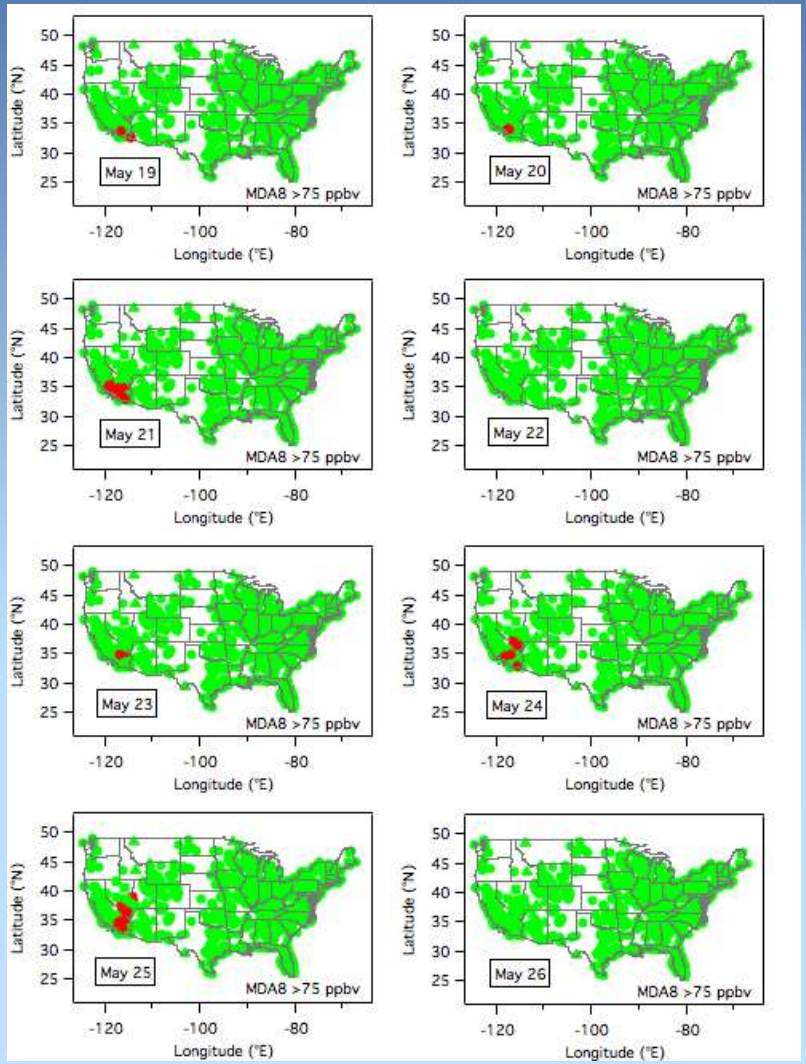


2008 (>75 ppbv)



2015 (>70 ppbv)

Impact on NAAQS compliance



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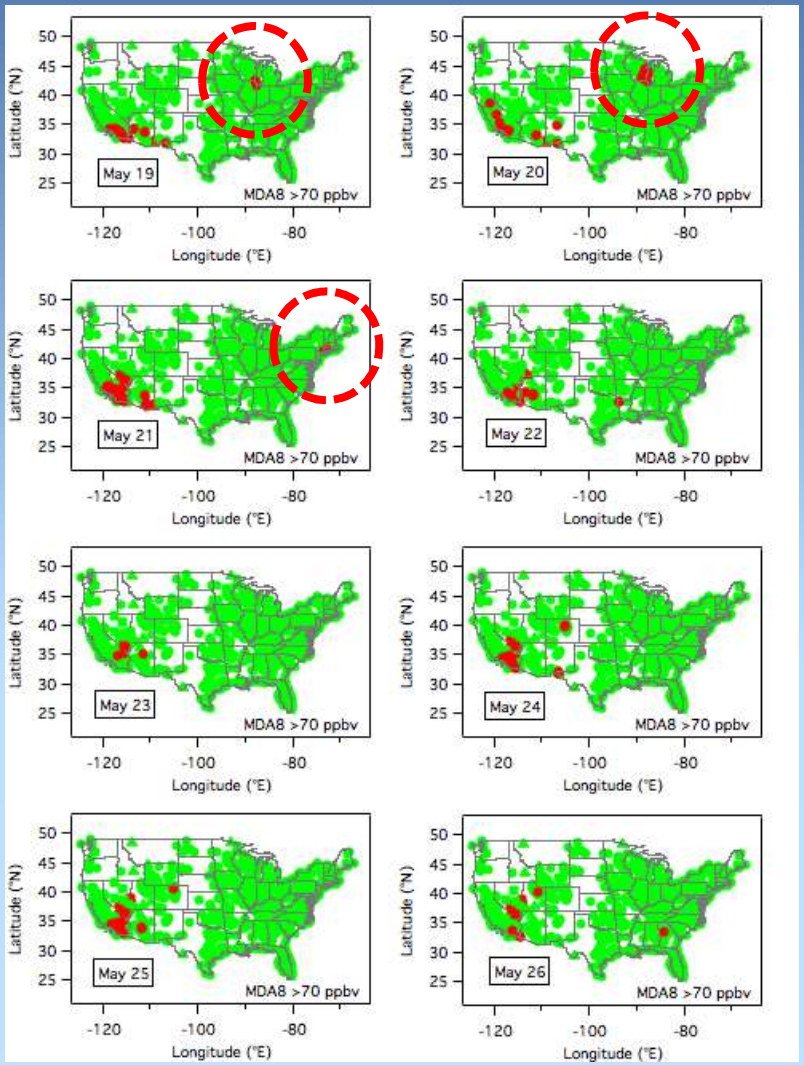
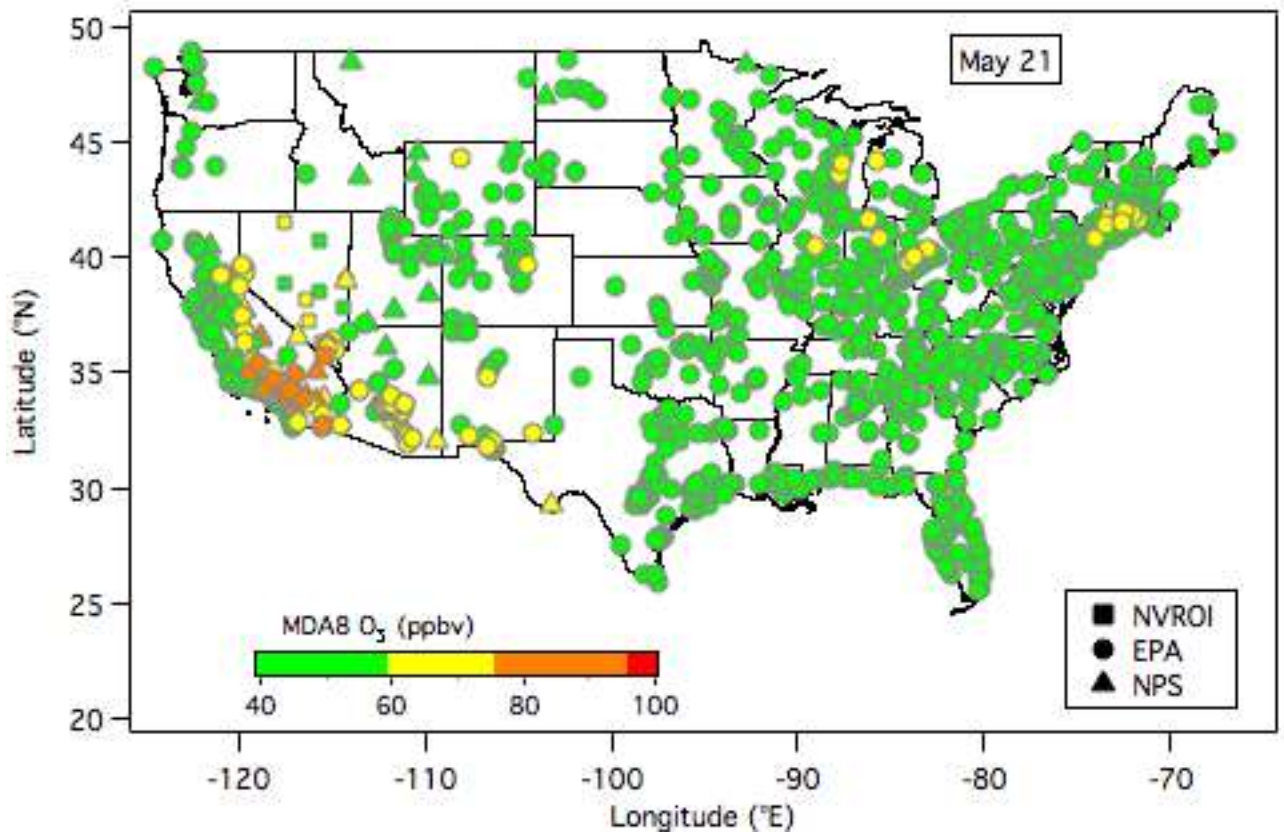
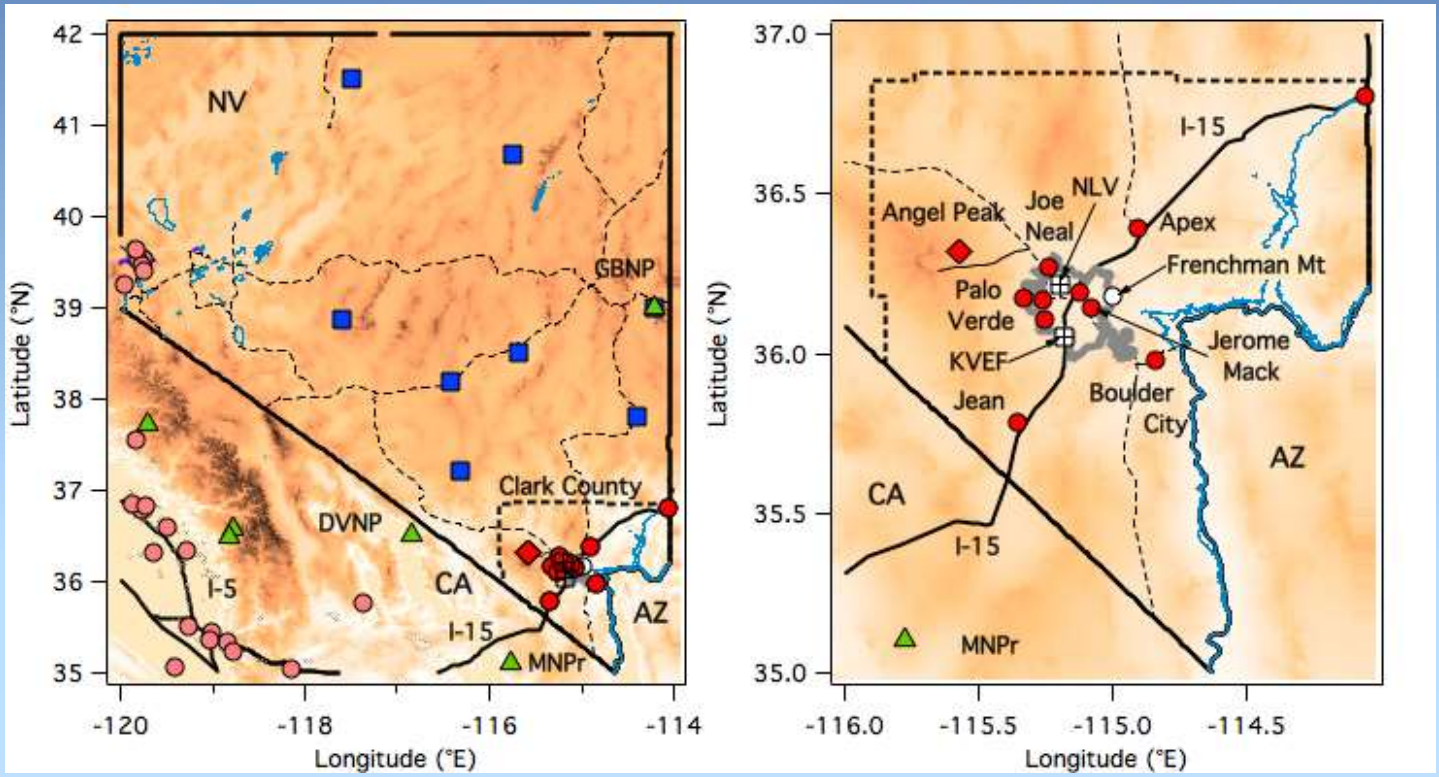


2015 (>70 ppbv)

Surface ozone on May 21, 2013



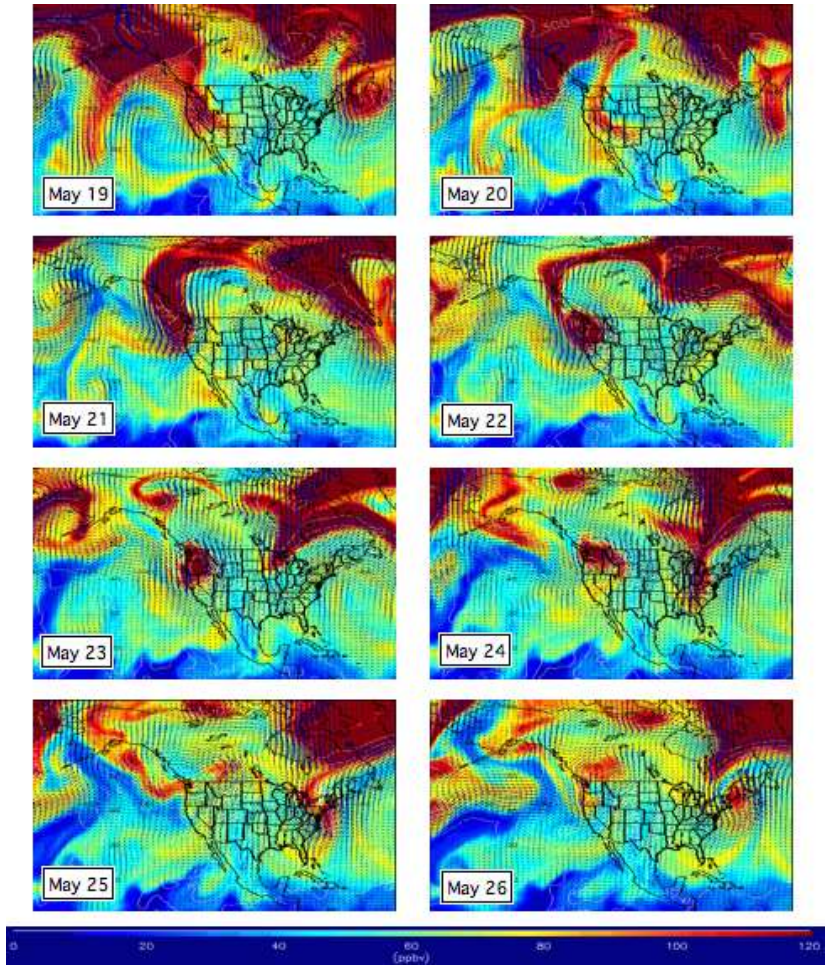
Surface ozone monitors in the SW



STOP

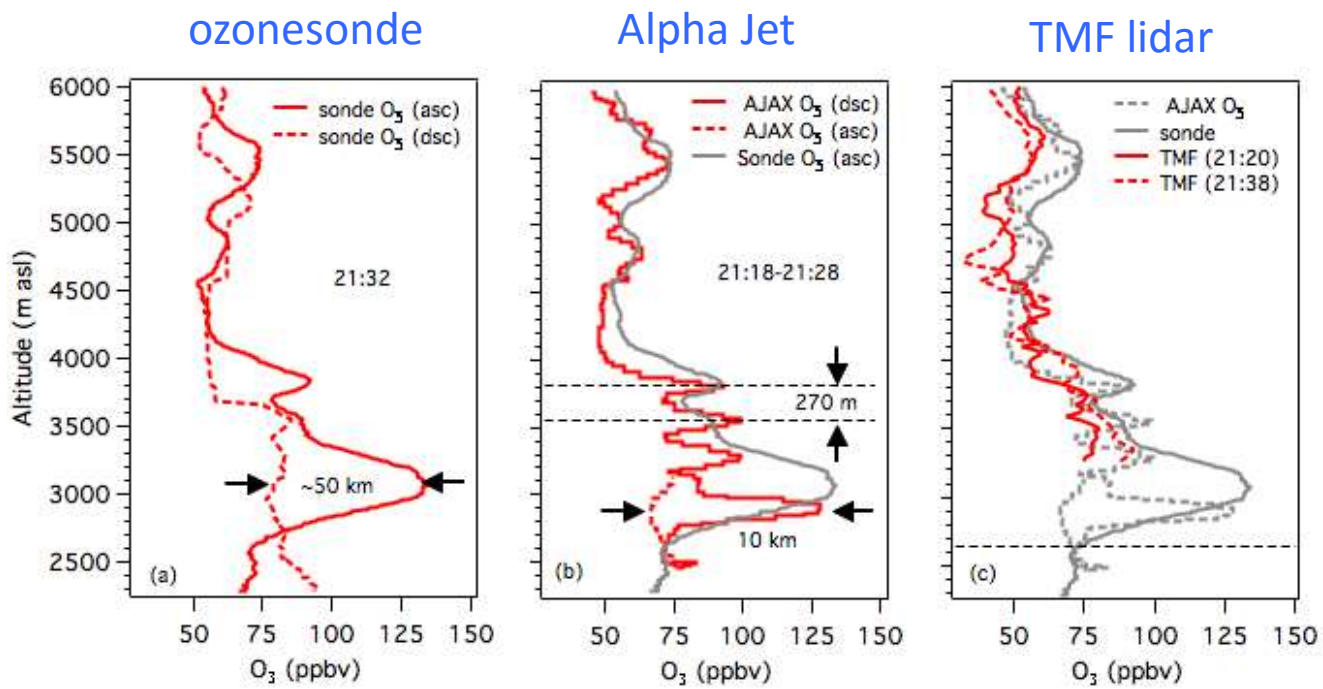
Synoptic Background (May 19-26, 2013)

NOAA/NESDIS RAQMS 12UT 310K O_3 distributions (Brad Pierce)



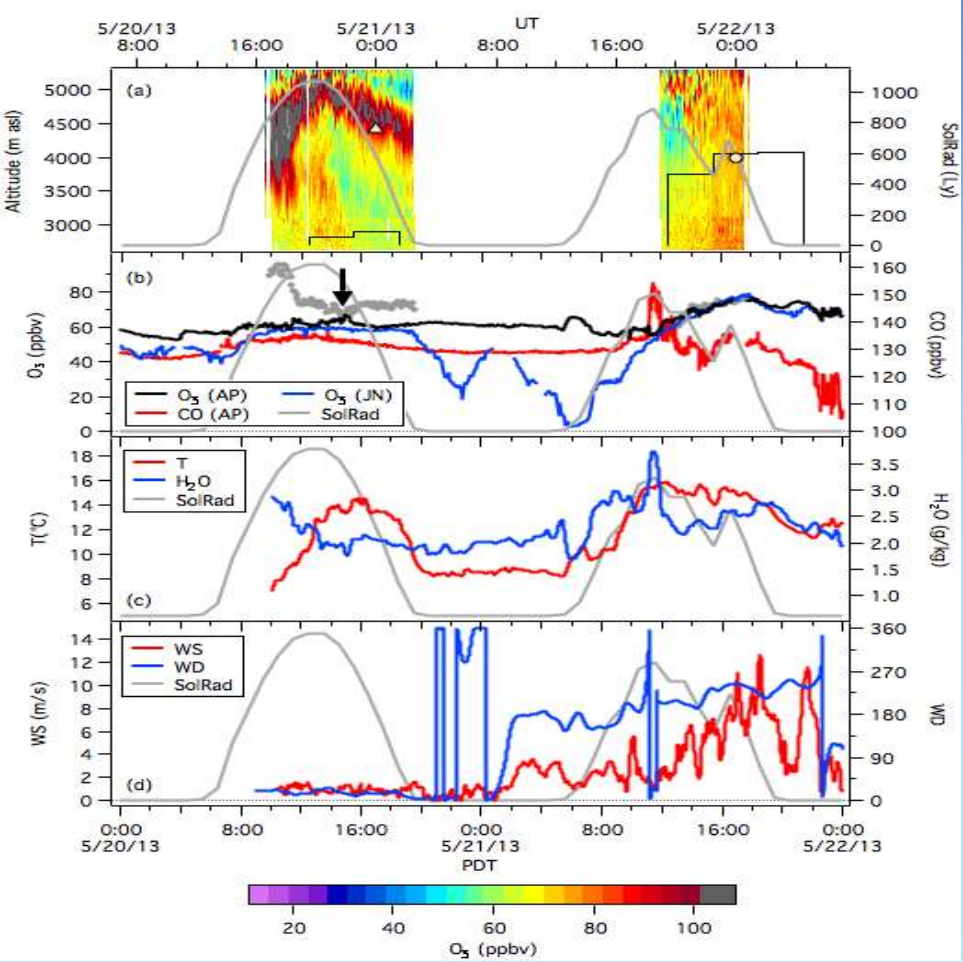
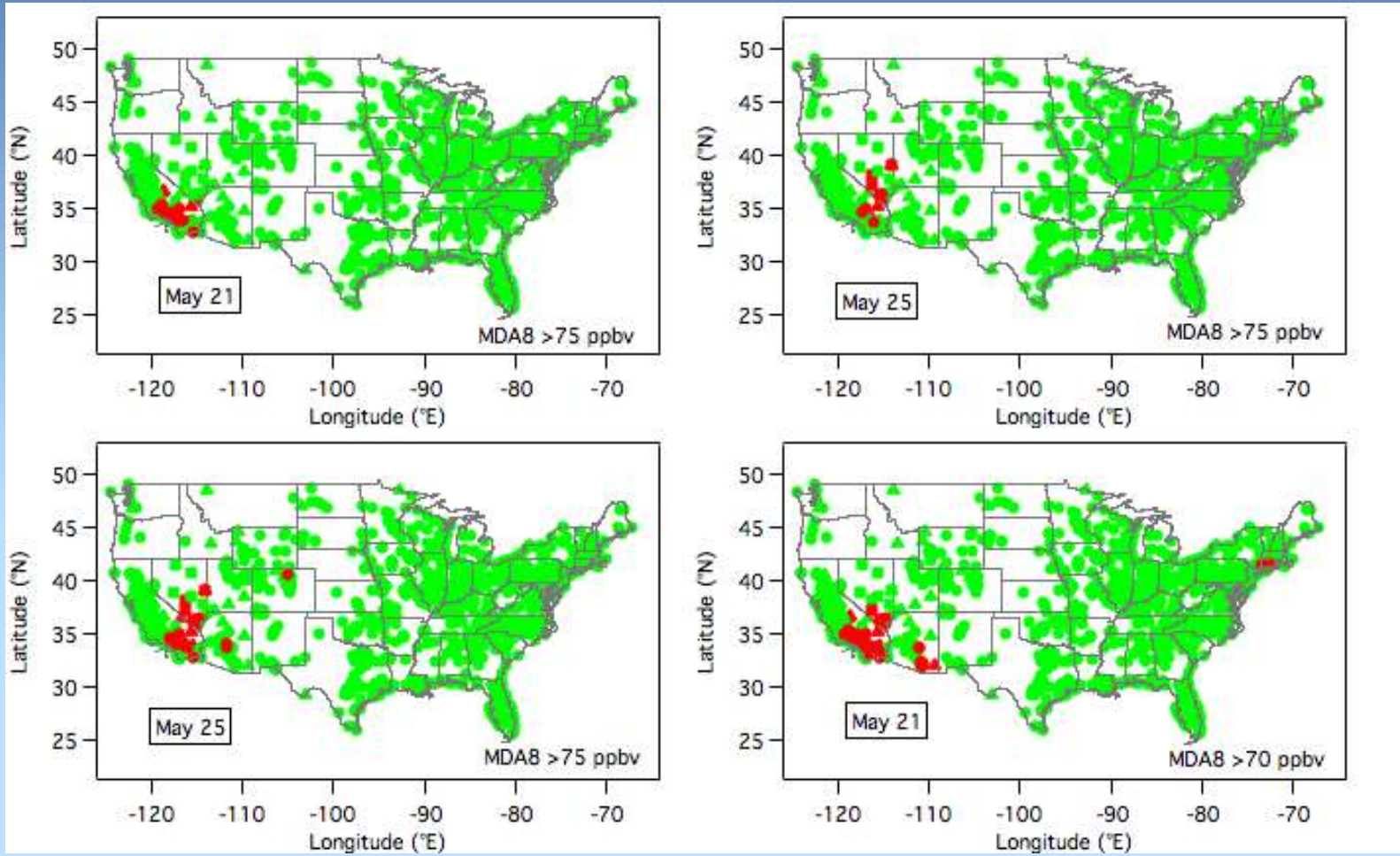
Multiple high O_3 filaments above U.S.

Ozone profiles above TMF on May 24, 2013



Small-scale structures above TMF caused by topographically forced gravity waves

May 20-21, 2013



Impact on NAAQS compliance